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AERONAUTICS

FOURTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1918

FILE COPY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

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TECHNICAL REPORTS.[1]

[1] Reports 1-7, inclusive, published in First Annual Report; 8-12, inclusive, in Second Annual Report; 13-23, inclusive, in Third Annual Report.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

FOURTH STREET AND MISSOURI AVENUE, WASHINGTON, D. C.

Dr. John R. Freeman, *Chairman*,
Grosvenor Building, Providence, R. I.

Dr. S. W. Stratton, *Secretary*,
Bureau of Standards, Washington, D. C.

Dr. Charles D. Walcott, *Chairman Executive Committee*,
Secretary Smithsonian Institution, Washington, D. C.

Dr. Joseph S. Ames,
Johns Hopkins University, Baltimore, Md.

Dr. William F. Durand,
Leland Stanford Junior University, California.

Dr. John F. Hayford,
Northwestern University, Evanston, Ill.

Maj. Gen. William L. Kenly,
Director of Military Aeronautics, Washington, D. C.

Prof. Charles F. Marvin,
Chief United States Weather Bureau, Washington, D. C.

Dr. Michael I. Pupin,
Columbia University, New York City.

Dr. Wallace C. Sabine,
Bureau of Aircraft Production, Dayton, Ohio.

Rear Admiral David W. Taylor,
Chief Constructor, United States Navy, Navy Department, Washington, D. C.

Commander John H. Towers,
Navy Department, Washington, D. C.

EXECUTIVE COMMITTEE.

Dr. Charles D. Walcott, *Chairman*.
Dr. S. W. Stratton, *Secretary*.

Dr. Joseph S. Ames.
Dr. John F. Hayford.
Prof. Charles F. Marvin.
Rear Admiral D. W. Taylor, United States Navy.
Dr. John R. Freeman.
Maj. Gen. W. L. Kenly, United States Army.
Dr. W. C. Sabine.
Commander John H. Towers, United States Navy.

MESSAGE OF THE PRESIDENT.

To the Senate and House of Representatives:

As required by the provisions of the act of March 3, 1915, making appropriations for the naval service for the fiscal year ending June 30, 1916, I transmit herewith the fourth annual report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1918.

The recommendation of the committee as outlined in the closing paragraphs of its report for the continuance of the scientific study of the problems of flight and the development of aviation for all purposes has my hearty approval. Attention is also invited to the recommendation of the committee that the appendixes of this report be published with the report as a public document.

WOODROW WILSON.

THE WHITE HOUSE, *December, 1918.*

LETTER OF SUBMITTAL.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 29, 1918.

The PRESIDENT:

In compliance with the provisions of the act of Congress, approved March 3, 1915 (naval appropriation act, Public No. 273, 63d Cong.), the National Advisory Committee for Aeronautics has the honor to submit herewith its fourth annual report, including a statement of the expenditures to June 30, 1918.

Attention is invited to the appendixes to the committee's report, and it is recommended that they be published with the report of the committee as a public document.

The committee desires especially to invite your attention to the closing paragraphs of its report, and trusts that its recommendations for the continuance of the scientific study of the problems of flight and for the development of avaition for all purposes may have your pproval.

Very respectfully,

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
C. D. WALCOTT, *Chairman Executive Committee.*

COPY
To be returned to
the files of the Langley
Memorial Aeronautical
Laboratory.

FOURTH ANNUAL REPORT OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 29, 1918.

To the Congress:

In accordance with the provisions of the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its fourth annual report. This report reviews the activities of the committee during the past year, the work accomplished in the study of scientific problems relating to Aeronautics, the assistance rendered by the committee in the examination of aeronautical inventions, and in the collection and distribution of scientific and technical data from abroad, and contains a statement of expenditures, estimates for the fiscal year 1920, and certain recommendations for the consideration of Congress. Technical reports covering the various subjects under investigation during the past year are submittted as appendixes.

THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

The National Advisory Committee for Aeronautics was established by Congress by act approved March 3, 1915. Under the law the committee is charged with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of the problems which should be experimentally attacked, their investigation and application to practical questions of aeronautics. The committee is also authorized to direct and conduct research and experiment in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

The committee has twelve members, appointed by the President. As authorized by Congress, the personnel of the committee consists of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, of the United States Weather Bureau, and of the United States Bureau of Standards; and not more than five additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences.

During the past year Maj. Gen. George O. Squier, Chief Signal Officer of the Army, and Lieut. Col. V. E. Clark, Signal Corps, were succeeded on the committee by Maj. Gen. William L. Kenly, Director of Military Aeronautics, and Dr. Wallace C. Sabine, of the Bureau of Aircraft Production. Hon. Byron R. Newton resigned and was succeeded on the committee by Dr. John R. Freeman, of Providence, R. I.

The full committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 4, 1917, and that held on October 10, 1918.

At the annual meeting held on October 10, 1918, the policy was adopted that no member should serve as chairman for more than two consecutive terms. Dr. John R. Freeman was elected chairman to succeed Dr. William F. Durand, who had served two terms as chairman.

The organization of the Advisory Committee as of October 10, 1918, the date of the annual meeting, is as follows:

Dr. John R. Freeman, chairman.

Dr. S. W. Stratton, secretary.

Dr. Charles D. Walcott, chairman executive committee.
Dr. Joseph S. Ames.
Dr. William F. Durand.
Dr. John F. Hayford.
Maj. Gen. William L. Kenly, United States Army.
Prof. Charles F. Marvin.
Dr. Michael I. Pupin.
Dr. Wallace C. Sabine.
Rear Admiral David W. Taylor, United States Navy.
Commander John H. Towers, United States Navy.

AMENDMENTS TO REGULATIONS.

At the semiannual meeting on April 18, 1918, amendments to the regulations were adopted, which were approved by the President under date of May 20, 1918, which provided officially for the position of assistant secretary, and in accordance therewith Mr. John F. Victory was appointed assistant secretary.

THE EXECUTIVE COMMITTEE.

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include further any member of the Advisory Committee not otherwise a member of the executive committee, but resident in or near Washington and giving his time wholly or chiefly to the special work of the committee. The executive committee, as elected and organized on October 10, 1918, is as follows:

Dr. Charles D. Walcott, chairman.
Dr. S. W. Stratton, secretary.
Dr. Joseph S. Ames.
Dr. John R. Freeman.
Dr. John F. Hayford.
Maj. Gen. W. L. Kenly, United States Army.
Prof. Charles F. Marvin.
Dr. W. C. Sabine.
Rear Admiral D. W. Taylor, United States Navy.
Commander John H. Towers, United States Navy.

The executive committee, in accordance with the general instructions of the Advisory Committee, controls the administration of the affairs of the committee and exercises general supervision over all arrangements for research and other matters undertaken or promoted by the Advisory Committee.

The executive committee held regular monthly meetings throughout the year, and in addition held 12 special meetings on the following dates:

October 9, 1917; November 15, 1917; December 11, 1917; January 10, 1918; January 24, 1918; February 8, 1918; February 23, 1918; March 15, 1918; March 23, 1918; April 13, 1918; April 29, 1918; May 11, 1918; May 25, 1918; June 8, 1918; June 21, 1918; June 27, 1918; July 18, 1918; July 30, 1918; August 8, 1918; September 6, 1918; September 23, 1918; October 8, 1918; October 10, 1918.

The committee has organized the necessary small clerical and technical staffs for handling the work of the committee proper, all of which is performed under the personal supervision of one or more of the officers of the committee. The assistant secretary, who also serves as special disbursing agent, has charge of the office, records, and property of the committee.

SUBCOMMITTEES.

The following standing and special subcommittees have been organized under the executive committee. Reference to their specific functions and programs is contained elsewhere in this report. Under provision of the regulations for the conduct of the work of the committee the membership of subcommittees is not limited to members of the advisory committee. The committees marked with an asterisk (*) have been superseded or discharged:

STANDING COMMITTEES.

AIRCRAFT DESIGN AND ASSOCIATED ENGINEERING PROBLEMS:
- Dr. W. F. Durand, chairman.
- Dr. John F. Hayford, acting chairman.
- Dr. Joseph S. Ames.
- Naval Constructor J. C. Hunsaker, United States Navy.
- Lieut. Commander W. S. Burgess, United States Navy.
- Lieut. Alexander Klemin, A. S., A. P.
- J. H. DeKlyn.
- H. L. Whittemore.
- *Steel construction for aircraft*—
  - Dr. W. F. Durand, chairman.
  - Dr. S. W. Stratton.
  - Dr. A. F. Zahm.
  - F. G. Diffin.
  - W. B. Stout.
  - J. H. Nelson.
  - H. L. Whittemore.
- *Fireproof coverings*—
  - Dr. Joseph S. Ames, chairman.
  - H. D. Gibbs.
  - R. G. Dort.
  - W. H. Smith.
  - Lieut. H. A. Gardner, United States Naval Reserve Force.
  - H. L. Whittemore.

NAVIGATION OF AIRCRAFT, AERONAUTIC INSTRUMENTS AND ACCESSORIES:
- Dr. Joseph S. Ames, chairman.
- Dr. A. F. Zahm.
- M. D. Hersey.
- Col. T. H. Bane, United States Army.
- Maj. C. E. Mendenhall, A. S., A. P.

POWER PLANTS FOR AIRCRAFT:
- Dr. S. W. Stratton, chairman.
- L. M. Griffith, vice chairman.
- Dr. H. C. Dickinson, secretary.
- Herbert Chase.
- Prof. E. C. Newcomb.
- Prof. G. W. Lewis.
- Lieut. C. F. Taylor, U. S. N. R. F.
- *Fuel injection engine*—
  - L. M. Griffith, chairman.
  - Dr. H. C. Dickinson.
  - Prof. E. C. Newcomb.
  - H. G. Chatain.
  - P. L. Scott.
  - H. Lemp.

STANDARDIZATION AND INVESTIGATION OF MATERIALS FOR AIRCRAFT:
- Dr. S. W. Stratton, chairman.
- Dr. G. K. Burgess.
- E. D. Walen.
- Dr. Fred W. McNair.
- Naval Constructor J. C. Hunsaker, United States Navy.
- Col. T. H. Bane, United States Army.
- *Light alloys*—
  - Dr. G. K. Burgess, chairman.
  - Maj. G. L. Norris, A. S., A. P.
  - C. M. Blough.
  - Z. Jeffries.
  - Prof. C. H. Mathewson.
  - Naval Constructor J. C. Hunsaker, United States Navy.

SPECIAL COMMITTEES.

*AERO TORPEDOES:
- Commander J. H. Towers, United States Navy, chairman.
- Lieut. Col. V. E. Clark, A. S., A. P.

*AIRCRAFT COMMUNICATIONS:
- Dr. Michael I. Pupin, chairman.
- Dr. Joseph S. Ames.
- Dr. S. W. Stratton.
- Dr. E. B. Rosa.

*AIRPLANE MAPPING COMMITTEE:
- Maj. Gen. George O. Squier, United States Army, chairman.
- Dr. Charles D. Walcott.
- Capt. J. W. Bagley, Engineer Officers' Reserve Corps.
- Carl G. Fisher.

*BIBLIOGRAPHY OF AERONAUTICS:
- Prof. Charles F. Marvin, chairman.
- Dr. Joseph S. Ames.

BUILDINGS, LABORATORIES, AND EQUIPMENT.
- Dr. S. W. Stratton, chairman.
- Dr. Joseph S. Ames.
- Dr. W. F. Durand.
- Dr. L. J. Briggs.

CIVIL AERIAL TRANSPORT:
- Dr. W. F. Durand, chairman.
- Dr. S. W. Stratton.
- *Landing fields and flying routes—*
  - Col. H. M. Byllesby, United States Army, chairman.
  - Carl G. Fisher.
  - S. S. Bradley.
  - H. F. Talbott.
  - W. W. Montgomery.

*DESIGN, CONSTRUCTION, AND NAVIGATION OF AIRCRAFT:
- Dr. W. F. Durand, chairman.
- Dr. Joseph S. Ames.
- Commander J. H. Towers, United States Navy.
- Lieut. Col. V. E. Clark, U. S. A. S., A. P.
- Dr. A. F. Zahm, secretary.
- Frederick Alger.
- M. D. Hersey.
- J. H. Nelson.
- **Aeronautic instruments—*
  - Dr. Joseph S. Ames, chairman.
  - Commander W. T. Jewell, United States Navy.
  - M. D. Hersey.
  - Maj. C. E. Mendenhall, A. S., A. P.
  - Dr. L. J. Briggs.

EDITORIAL:
- Dr. Joseph S. Ames, chairman.
- Dr. W. C. Sabine.
- Dr. S. W. Stratton.
- Dr. W. F. Durand.
- Prof. Charles F. Marvin.
- Lieut. H. B. Luther, United States Navy.

FREE FLIGHT TESTS:
- Dr. John F. Hayford, chairman.
- Dr. W. F. Durand.
- Dr. S. W. Stratton.
- Dr. L. J. Briggs.
- Dr. A. F. Zahm.
- Fred W. McNair.
- Lieut. Alexander Klemin, A. S., A. P.
- Capt. D. L. Webster, A. S., A. P.

GOVERNMENTAL RELATIONS:
Dr. Chalres D. Walcott, chairman.
Dr. S. W. Stratton.
*HELICOPTER, OR DIRECT-LIFT AIRCRAFT:
Dr. W. F. Durand, chairman.
Dr. Michael I. Pupin.
M. B. Sellers.
Dr. A. F. Zahm.
Prof. E. B. Wilson.
*NOMENCLATURE FOR AERONAUTICS:
Dr. Joseph S. Ames, chairman.
Dr. H. C. Dickinson.
Lieut. H. B. Luther, United States Navy.
Lieut. Col. V. E. Clark, A. S., A. P.
PERSONNEL:
Dr. Joseph S. Ames, chairman.
Dr. S. W. Stratton.
Dr. John F. Hayford.
RELATION OF ATMOSPHERE TO AERONAUTICS:
Prof. Charles F. Marvin, chairman.
Dr. John F. Hayford.
W. R. Gregg.
*SPECIAL COMMITTEE ON ENGINEERING PROBLEMS:
Dr. W. F. Durand, chairman.
Dr. S. W. Stratton.
Dr. A. F. Zahm.
Dr. H. C. Dickinson.
Herbert Chase.
Grover C. Loening.

FUNCTIONS OF THE COMMITTEE.

The functions of the committee are stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of problems in this field with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

In the following general manner the various standing subcommittees of the executive committee deal with subject matters:

(1) The subcommittee on aircraft design and associated engineering problems deals with the general aerodynamic problems of flight, and with the fundamental problems of the design of structures suited to realize the various requirements of the particular service required. To assist in its work subcommittees on steel construction for aircraft and fireproof coverings for aircraft have been organized.

(2) The subcommittee on navigation of aircraft, aeronautic instruments, and accessories deals with problems relating to instruments and accessories required for the operation and navigation of aircraft in general, and further with reference to special types of military or general service.

(3) The subcommittee on power plants for aircraft deals with problems relating to the power plant as a whole, and with its various immediate attachments and accessories, including fuels and lubricating oil. To assist in its work it has organized under it two subcommittees dealing specifically with the following subjects:

(a) Fuel injection engines.
(b) Radiators for aircraft engines.

(4) The subcommittee on standardization and investigation of materials deals primarily with the physical properties of the materials of engineering construction, with special reference to their adoption and use in aircraft construction. To assist in its work it has organized a subcommittee on light alloys, to deal specifically with aluminum and its light alloys.

COORDINATION OF SCIENTIFIC AND RESEARCH WORK.

By virtue of the close contact with military and naval needs afforded by the appointment of representative officers of the Army and Navy on the various subcommittees, and also by virtue of direct military and naval representation on the executive committee, the scientific and research work in aeronautics undertaken by the Army, the Navy, the Bureau of Standards, and this committee, has been coordinated. The results obtained have been promptly brought to the attention of all agencies interested and unnecessary duplication of effort has been reduced to a minimum.

The Director of the Bureau of Standards has placed the facilities, personnel, and equipment of the bureau at the service of the committee, and has requested the committee, through direct advice, and through the immediate agency of its various subcommittees to supervise and direct the research and investigational work on aircraft problems, carried on at the Bureau of Standards for the War and Navy Departments and the committee.

ACTIVITIES OF THE TECHNICAL SUBCOMMITTEES.

The activities of the subcommittees engaged on scientific and research problems and the programs for the further study of these problems are described as follows:

AIRCRAFT DESIGN AND ASSOCIATED ENGINEERING PROBLEMS.

During the past year the work of the subcommittee on aircraft design and associated engineering problems has, in the main, consisted of—

1. Investigation of designs for aircraft submitted to the committee.
2. Theoretical investigations.
3. Study of types of propellers.

1. Numerous designs of both airplanes and airships have been submitted to the committee. These have all been studied with care. In some cases special committees have been formed, with the cooperation of the military authorities, for the purpose of a more complete investigation.

In not a few cases features have been observed which called for further scientific research, and the committee has arranged for the necessary experiments in some of the existing aerodynamic laboratories, generally at the Bureau of Standards. Among these investigations the most important one, which is still in progress, is probably that of airplanes having wings arranged in tandem.

2. Several theoretical investigations have been undertaken. The most important of these are—

(*a*) The Study of the Laws of Air Resistance of Aerofoils, by George de Bothezat. (See Technical Report No. 28.)

(*b*) Theory of an Airplane Encountering Gusts, Part III, by Prof. E. B. Wilson. (See Technical Report No. 27.)

(*c*) The Design of Wind Tunnels and Wind Tunnel Propellers, by E. P. Warner and F. H. Norton.

(*d*) Analysis of Fuselage Stresses, by E. P. Warner and R. G. Miller.

3. The study of types of propellers has been continued at the aerodynamical laboratory of Leland Stanford Junior University. The laboratory itself and the results obtained in 1917 are described in the third annual report. The work of the present year has consisted in the investigation of many new types suggested, in the main, by the military authorities.

Before stating the program of work for the coming year it may be well to outline the scope of activities of the committee as conceived by its chairman and members. This may properly be subdivided into five groups of investigations: (1) Propellers; (2) aerofoils, or elementary supporting and controlling surfaces; (3) combinations of supporting and controlling surfaces; (4) reaction between the airplane and the propeller system; (5) structure. Under division 1 the principal problems are as follows:

(*a*) Model experiments: (1) On propeller models (single or multiple) undisturbed by reaction with adjacent structures.

(2) On propeller models (single or multiple) set up with corresponding models of adjacent and interfering structures.

(*b*) Free flight tests on full size propellers with special reference to the preceding experiments.

(*c*) Analytical investigation of propellers in accordance with theories developed by Drzewiecki, De Bothezat, and others, and with special reference to development of relations between the results found by such methods and those furnished by direct test, either on models or on full-size forms.

(*d*) Examination and analysis of existing experimental results on propeller models with a view to classification and reduction to uniform units and modes of representation.

Under division 2 the principal problems are as follows:

(*a*) Examination and analysis of existing experimental results on aerofoil and supporting or control surfaces with a view to classification and reduction to uniform units and modes of representation.

(*b*) Search for forms of aerofoil or supporting and control surfaces with special characteristics, as, for example, the minimum shift of center of pressure with change in angle of attack. This involves both theoretical and experimental study.

Under division 3 the principal problems are as follows:

(*a*) Study of combinations of supporting surfaces with a view to the determination of mutual reaction and interference.

(*b*) Study of combinations of supporting and of control surfaces with a view to the determination of the most effective methods of steering and of control generally, including stability under various conditions of flight.

Under division 4 the principal problems are as follows:

(*a*) The mutual reaction between a single propeller (tractor or pusher) and the adjacent structures of the plane (fuselage, nacelle, control surfaces).

(*b*) The mutual reaction between two tandem propellers and between such a pair of propellers and the adjacent plane structures (nacelle, fuselage, control surfaces).

Under division 5 the principal problems center around a study of the methods of design best suited to meet the needs of aeronautic construction and having in view:

(*a*) The available materials of engineering construction.

(*b*) The special requirements of aircraft structures.

Under these various problems those which correspond most nearly to the present resources of the committee, both in personnel and in laboratory equipment, are those in the first four groups; and of these the problems of more immediate importance seem to be the following: 1a (II), 1b, 1c, 1d; 2a, 3a, 4a; 4b.

In the determination of precedence, however, judgment has been constantly exercised, having in view the application of the problem to war conditions, and the available resources of the committee.

With the opening of the laboratory at Langley Field and the completion of the new wind tunnel in connection with it, the work of the committee will be greatly facilitated.

NAVIGATION OF AIRCRAFT, AERONAUTIC INSTRUMENTS, AND ACCESSORIES.

A subcommittee on navigation of aircraft, aeronautic instruments, and accessories was formed in order to aid in the development of airplane instruments; but inasmuch as there were established at almost the same time by the aviation section of the War and Navy Departments divisions with similar duties, the work of the committee has been of necessity limited.

During the past year the activity of the committee may be considered under three heads:

1. *Improvements in existing instruments.*—Owing to the fact that the aviation officers of the Army and Navy have to a large degree handled their problems in their own organizations, it has been only in rare cases that it was necessary to conduct independent investigations looking to the improvement of existing instruments. The method followed has been to learn from the military authorities the nature of the defects found to exist in the standard instruments furnished the airplanes; then to ascertain if investigations were being made to remedy these defects. In those cases where additional researches were necessary, proper steps have been taken to see that these were made at the Bureau of Standards, the resources of which were placed at the disposal of the committee by its director.

2. *New instruments.*—Constant efforts have been made to obtain information concerning the airplane instruments developed in foreign countries, and in a number of cases actual instruments have been obtained. These have been tested, and the results, if favorable, have been transmitted to the proper military authorities.

Continuous correspondence has been carried on with French and British experts and investigators in order to keep in touch with developments in Europe, especially with reference to long-distance operations.

3. The great number of inventions and suggestions which are received by the office of the National Advisory Committee for Aeronautics are carefully scrutinized; and in case any promising device or method is noted, care is taken to further its development. When it is perfected, or its usefulness demonstrated, it is called to the attention of the military authorities.

The great defect in the proper conduct of the obvious work of the committee at the present time is the lack of facilities for testing instruments in actual flight and for learning from the aviators themselves the facts about the instruments. For the committee to work to advantage it will be necessary for it to have a laboratory for instruments directly attached to an aviation field and to enjoy certain obvious privileges in connection with the latter. This matter will be settled satisfactorily when the laboratory, workshop, and wind tunnel are opened at Langley Field, for the hearty cooperation of the Division of Military Aeronautics is assured.

The program for the following year will be largely a continuation of that for the present year, viz:

1. Investigations will be undertaken aimed to improve the standard instruments which prove unsatisfactory.

2. Efforts will be made to develop new instruments to meet needs as they arise or as they may be foreseen.

3. As soon as proper facilities are provided at Langley Field an independent investigation will be begun as to proper standards and specifications for airplane instruments of all types.

During the current year there has been no allotment of funds to carry on the work of the committee, but in the near future it will be necessary to provide for the salaries of two or more technical assistants and for construction work in the shops.

POWER PLANTS FOR AIRCRAFT.

New types of aviation engines.—A special subcommittee known as the fuel injection engine committee was appointed to investigate the possibilities of developing an aircraft engine embodying features of the Diesel or Junkers-Diesel oil engines. Some progress was made in the design of such an engine, and the committee has cooperated with a private company which is developing a simplified form of Junkers engine for a somewhat different purpose. The possibilities inherent in this type of engine appear so promising that it is planned to continue the work on this problem.

A novel form of scavenging two-cycle engine was brought to the attention of the committee early in the year and appeared so promising that the Clarke Thomson Research was interested in the problem of its development. A standard aircraft engine was altered to suit the principles involved. The results of experimentation and test, however, indicated that the inherent difficulties were too great to justify continuation of the development in the face of the more important problems then requiring prompt attention. It is planned to again resume this investigation in the near future, as the possible results are of great interest.

Supercharging to maintain power at altitude.—The committee has kept in close touch with the several forms of apparatus which are being developed for this purpose. Early in the year a comprehensive survey was made of the various possible means for maintaining the charge density, and it was concluded that all but one of the promising types were under satisfactory development and that the committee could best expedite the final solution by insuring that the one remaining interesting type was made the subject of intensive development. Therefore the Clarke Thomson Research was requested to undertake the problem of supercharging by means of the gear-driven positive blower of the Roots type. Test results are not yet available. It is the intention to maintain close cognizance of all forms of supercharging development and to insure that the true value of every promising means shall be determined.

Improvement of engine details.—Inasmuch as the life of most aeronautic engines depends to a large extent upon the maintenance of the exhaust valves in a proper working condition and that the principal reason for the rapid deterioration of such valves in the high temperature at which they have to operate, it is readily seen that the adequate control of the temperature rise of exhaust-valve heads constitutes a major problem. The possibilities of several suggested remedies for this trouble have been studied and experiments have been conducted with valves of various designs and materials. It is proposed to continue this investigation with a view to determining the best means for insuring the maximum life of such parts.

The problem of suppressing the noise of the exhaust has been studied and much experimental work performed in the endeavor to devise a satisfactory form of muffler for aircraft engines. Very encouraging results have been obtained with a newly developed vortex type of silencer.

Radiation improvement.—A very comprehensive study of the characteristics of all available types of radiator-cell construction has been made in three different types of wind tunnels. Experimental work has been completed and results analyzed to the end that the underlying principles of radiator design have been established. In practice the problem is fundamentally one of minimizing the power cost of unit radiation, and this investigation has resulted in several reports which contain especially valuable engineering data. The effect of radiator location on the airplane and of different forms of radiator housing have also been studied, with some rather remarkable results. It is proposed to check the laboratory data by various free flight tests and also to make an additional laboratory study at such points as the effect of cell size, dimensions, and nature of surface on the rate of heat transfer.

Carburetor improvement.—A study has been made of the performance of several different types of aeronautic carburetors as mounted upon an engine in the altitude chamber. At the same time, these and other types have been studied with the aid of a special testing equipment which permitted duplication of the pressure and temperature conditions encountered at all flying altitudes. Special attention has been given to the study and evaluation of the several available methods for compensation, in the endeavor to secure automatic or inherent maintenance of correct mixture proportions under the greatly varying temperatures and pressures encountered.

Two types of automatic carburetor control have been developed to such a point that their operation is superior to any available hand adjustment. A third method is now under developement and promises excellent results. It is proposed to continue this investigation of means for automatically compensating for altitude and to make a special effort to discover means of compensation which will be inherent in their nature and therefore will not depend upon moving parts for their functioning.

Some time has been devoted to the study of the atomization of the fuel, in the belief that improvement in this direction is of the greatest importance in bettering both the power output and the thermal efficiency. The problem of satisfactorily determining the figures of merit to be awarded to different carburetors, on the basis of completeness of atomization in the mixtures delivered by them, is one of great difficulty and it has not been possible during the stress of the past year to develop methods or apparatus for the measurement of the quantities involved. It is proposed, however, to pursue this investigation as rapidly as may be possible.

Ignition improvement.—Methods have been developed for the mechanical and electrical testing of those components of the ignition system which had not previously received adequate treatment. The spark plug in particular has been made the subject of exhaustive research as to its design, materials, and operation characteristics. An extensive investigation has been conducted on the effect of high temperatures upon the mechanical and electrical properties of various ceramic and other materials which could be used for insulators. As the result of a most careful survey of the entire field of ceramic materials, in which a very large number of new porcelains were made and tested, a special porcelain has been developed for spark-plug insulators which is markedly superior to any that has heretofore been produced, either in this country or abroad. The electrical, thermal, and mechanical strength of this material so far surpasses that of the best previously available as to make this discovery one of the greatest possible importance.

The several causes of failure in spark plugs have been investigated, according to their relative importance, and temperature measurements have been made to determine the effect of different materials in the spark-plug shells.

Studies have been made of the effect of changes of pressure and temperature upon the voltage necessary to insure sparking. A method has been developed for measuring the heat energy of ignition sparks and corresponding tests have been made upon a number of ignition systems. At the same time the character of the electrical discharge has received much attention as has also the problem of determining magneto characteristics. The effect of the external spark gap, and the correct design of such accessory has been made the subject of considerable study with a view to determining the best design for a simplified form which would render unnecessary any manual adjustment, in order to secure the correct electrical characteristics under varying conditions. The problem of determining the most effective form of electrical discharge for securing the greatest rapidity of ignition and flame propagation is to be further studied as are those other problems which have been mentioned above.

Fuels and combustion.—An exceptionally complete program of investigation has been completed on the performance characteristics of a considerable number of gasolines and other hydrocarbon fuels as developed under conditions approaching those obtained in actual flying, but which were secured by means of the altitude chamber. While the results of this extended investigation are largely of a negative nature, they have nevertheless been of the greatest importance in the settling of many questions involving supposed advantages for fuels of extraordinary specifications or compositions. However, certain fuel mixtures and chemically altered fuels have shown extremely desirable characteristics, largely by way of permitting greatly increased compression pressures and therefore increased power output and thermal efficiency.

An engine has been equipped with a new form of apparatus which will enable the determination of absolute values of the rate of flame propagation. It is also expected that it will be possible to measure the rate of combustion. It is proposed that this apparatus shall furnish data with which to explain the differences between the performances of various fuels, as obtained in the altitude chamber, and which have been impossible to connect with any of the ordinary properties of the fuels tested.

Three special gas-engine indicators have been under development. A sensitive diaphragm indicator with minimum inertia errors has been constructed especially for use in the altitude chamber. This instrument permits the recording mechanism to be operated outside the test chamber at a considerable distance from the engine. Records are made mechanically in rectangular coordinate. A self-contained indicator making records of minute size in rectangular coordinate has been designed with a view to convenience of installation. No connection is required to the moving parts of the engine. Records of successive cycles are made in series on a transparent film and afterwards are magnified optically 100 to 200 diameters for study.

A greatly improved and simplified form of optical indicator of the polar type has been designed with which it is hoped to obtain pressure diagrams of great accuracy and which can be used in connection with flame-propagation measurements in the study of the phenomena which occur in the cylinder of the modern aircraft engine. This work is of great importance as determining the direction for the expenditure of effort in the further development of this type of prime mover, and it is intended to carry it on as rapidly as possible.

Lubrication and lubricants.—A preliminary study has been made of effect of varying oil compositions upon the power output, efficiency, and operating characteristics of aircraft engines as far as could be determined by the ordinary methods of conducting such tests. The effect of the mixture of different forms of graphite with the oil has also been studied. These tests were what might be called service tests, inasmuch as service engines were used and operated under full load conditions on the torque stand, samples of the oil being obtained at regular intervals and the change in quality noted, as well as the operating ch racteristics of the engine.

A special single cylinder aircraft engine has been fitted with means for measuring the pressures and temperatures existing in the oil films at all of the important bearing points. This equipment will provide original data of a character which has not heretofore been obtainable, and it is believed that the very complete knowledge thus secured of the actual conditions in the oil film will enable a much more accurate determination of the properties required in oils for aircraft engine lubrication.

A comprehensive laboratory study is being made of the fundamental properties of lubricants and new kinds of tests have been discovered which throw much light upon the complicated relations existing between the various physical and chemical properties of lubricants.

It is proposed to continue all of the above phases of this investigation, as much of the work is of a fundamental nature and the results will be of the greatest importance to other fields of lubrication as well as that of the high duty internal combustion engine.

Steam aircraft power plants.—Although the steam engine was very popular during the very early attempts to solve the problem of mechanical flight, the remarkable development of the internal combustion engine has so greatly surpassed that of the steam power plant that it had been impossible for the latter to approach the results obtained by the gasoline engine for the propulsion of aircraft, either from the standpoint of weight per horsepower output or thermal efficiency. At the present time, however, it is the belief of many aeronautic engineers that a large proportion of the future commercial aircraft will be of much greater size than have so far been constructed. In the larger of present day long-distance bombing airplanes the total power capacity approximates 2,000 horsepower. If steam power has any chance at all, in competition with the internal-combustion engine, it must be in units of large size. Owing to the long and expensive development through which the steam plant must pass and to the comparatively recent advent of the successful very large airplane it was impossible to undertake any comprehensive investigation of the problem during the year 1918. However, it is felt that the subject is well worthy of the most serious consideration during the immediate future and it is the intention to institute such laboratory and experimental activities as will serve to determine the fundamentals required for successful steam-power plants for aircraft.

Altitude laboratory.—The altitude laboratory, the construction of which was noted in the report for 1917, and which is more completely described in Technical Report No. 44 in this report, has been in continuous operation throughout the year. Observations have been made on the following relations, many of them in the most comprehensive and painstaking manner.

Effect of fuel composition on engine performance.
Changes of horsepower with altitude.
Changes of horsepower with speed at different altitudes.
Performance of carburetors with varying altitudes.
Heat distribution in engines.
Effect of supercharging.
Effect of compression ratio on horsepower at different altitudes.

As all of the above work was performed in connection with one or more of the problems above separately treated, it is unnecessary to repeat their discussion in this paragraph.

The program for the future utilization of the altitude laboratory includes, in addition to the work previously indicated, a study of the uniformity of mixture distribution in inlet manifolds of various types, a study of the effect of different compression ratios in connection with special fuels, tests, and development of supercharging devices, and analysis of a performance of different types of aircraft engines.

STANDARDIZATION AND INVESTIGATION OF MATERIALS FOR AIRCRAFT.

During the past year the activities of the subcommittee on standardization and investigation of materials for aircraft have been mainly conducted at the Bureau of Standards, and all experimental work on this subject done at the Bureau of Standards has been under the direction of this subcommittee. The following is a brief description of the more important work on this subject done at the Bureau of Standards during the past year:

(*a*) *Airplane wing beams.*—Tests have been made on solid beams of various woods with a view to determining their relative fitness for use as airplane wing spars. The possibility of using laminated beams has also been investigated. The use of built-up members will result in the elimination of much of the waste due to the necessary rejection of much solid stock. Various splices have been tried and recommendations made regarding the most successful types. The results of these tests are given in Technical Report No. 35. Further beam tests will be made on special apparatus for transverse and axial loading, thus eliminating expensive sand testing.

(*b*) *Wing ribs and wing coverings.*—Tests of wing ribs and wing coverings of metal and other materials are in progress, with the object of developing fireproof wings of lighter weight than the standard wing of fabric and wood.

(*c*) *Impact tests.*—An investigation is being made by means of impact tests of the effect of shocks on woods used in airplane construction. This method of testing woods for airplane use has been given but small consideration hitherto, and the data will no doubt be of considerable value.

(*d*) *Variable camber wing.*—A variable camber wing is being developed and tests on ribs designed for use in such a wing have given promising results.

STEEL CONSTRUCTION FOR AIRCRAFT.

The substitution of steel, or other metal, for spruce in airplane wing construction has been carefully considered both theoretically and practically.

Theoretical and experimental work was done at the Bureau of Standards, under the direction of Mr. John H. Nelson, by Mr. H. L. Whittemore, to whom should be credited the conclusions reached by the committee. The committee also carried on extensive investigations with the cooperation of the Empire Art Metal Co. at its factory at College Point, N. Y.

This resulted in the construction of two complete sets of metal wings which have been tested at McCook Field, Dayton, Ohio. These wings consisted of steel ribs and aluminum-alloy beams, the ailerons being entirely of steel.

These wings proved satisfactory under test both in flight and under load, so it is evident that a similar metal construction can be produced which will have the same strength as wood for equal weight.

A complete technical record of the experimental work on this most important subject is on file in the office of the committee, and the committee is at present encouraging development along several lines by various manufacturers.

FREE FLIGHT TESTS.

The general purpose of the work of the subcommittee on free flight tests is to obtain as complete tests as possible of the performance, in all respects, of airplanes while in the air under normal conditions. The general purpose of these tests is to supplement and make more valuable the information gained from all sorts of tests on the ground, including tests of engines and tests of airplane parts and airplane models in wind tunnels. It is obvious that the actual performance in the air, when it becomes known, is the best possible basis for future progress.

The committee now has, in a late stage of development, instruments for recording in the air the torque and revolutions per minute of the engine, the thrust of the propeller, the air speed, the angle of attack, and the inclination of the wing chord to the true horizon. It is proposed to complete this development as promptly as possible, and to get these instruments in action in the air, presumably on a D. H. 4 airplane, to determine the power-plant performance and the relations in the air between the lift, drag, air speed, and angle of attack.

When such tests have been successfully demonstrated as possible, by making them, the next steps on the program of the committee are to analyze the results and show what conclusions can be drawn from them.

The committee then proposes, in due time, to extend the free-flight tests to such quantities as will help to develop the stability characteristics of airplanes, possibly to furnish some information as to the structure of air, and also possibly to furnish information as to the stresses in various parts of an airplane in operation.

To secure the necessary degree of accuracy and reliability in the free-flight observations, the new instruments have in each case been so designed as to give a continuous autographic record.

RELATION OF THE ATMOSPHERE TO AERONAUTICS.

The functions of the subcommittee on the relation of the atmosphere to aeronautics are as follows:

(1) To advise in regard to those properties, characteristics, currents, winds, and the detailed meteorological conditions of the free air which are of special importance to aeronautics and the safety and economy of aerial navigation.

(2) To encourage the systematic investigation and observation, by means of kites, pilot balloons, airplanes, etc., of atmospheric phenomena; and through the agency of the Weather Bureau and otherwise to provide for the general dissemination of advices based upon observed atmospheric conditions, and to assist in the application of the results of investigations to the problems of aerial navigation.

The major activities of the subcommittee on the relation of the atmosphere to aeronautics have been confined to the program of work conducted by the Weather Bureau in observations and investigations of free-air conditions.

Provisions for the extension of this work were made by Congress in an item in the Army bill for the fiscal year ended June 30, 1918, which reads as follows:

> For the establishment and maintenance by the Weather Bureau of additional aerological stations for observing, measuring, and investigating atmospheric phenomena in aid of aeronautics, including salaries, travel, and other expenses in the city of Washington and elsewhere, $100,000, to be expended under the direction of the Secretary of Agriculture.

Prior to this time the Weather Bureau for a number of years had conducted free-air observations at Mount Weather and more recently at a central station at Drexel, Nebr. Under the above act, additional aerological stations were established at Broken Arrow, Okla., Ellendale, N. Dak., Groesbeck, Tex., Leesburg, Ga., and Royal Center, Ind. This distribution is as favorable as possible with the limited number of stations to secure observations of free-air conditions over a large portion of the country. Installation of equipment has been completed at the Ellendale station, and free-air observations were begun in December, 1917.

Much delay has been experienced in securing the equipment required for these stations, this equipment including special motor-driven kite-reeling apparatus installed in a shelter mounted on a circular track somewhat after the fashion of observatory domes of small dimensions. Nevertheless, encouraging progress has been made, and at the present date observations are actually being made at the stations at Drexel, Ellendale, and Royal Center. Hand flights have been made at Broken Arrow for two weeks and have just been begun at Groesbeck, pending the arrival of suitable motors.

The data thus obtained include observations of atmospheric pressure, temperature, humidity, wind direction and velocity, cloud altitude and movement, and, at Drexel, electric potential. Daily telegraphic reports of conditions at one or more selected levels have been sent to the forecast center of the bureau at Washington, D. C., on all days when flights were made. At Drexel, in addition to the daily flights, series of observations covering a period of about 30 hours have been made whenever conditions were favorable. The data thus obtained enable the Weather Bureau to follow in considerable detail the diurnal changes at different altitudes. In all, 478 observations have been made from July 1, 1917, to June 30, 1918. Of these, 134 were made in 18 different series, the remaining 344 being made as daily observations. The average altitude reached in all flights was about 3,000 meters. At Ellendale 163 flights were made from December 17, 1917, to June 30, 1918, the mean altitude being about 2,400 meters.

Publications.—Continuing the regular practice of the Weather Bureau, the data collected from the aerological stations are published as promptly as possible in the form of quarto supplements to the Monthly Weather Review. At the present date these comprise seven, namely, Aerology, Nos. 1 to 7, inclusive, and include data from Drexel and Ellendale up to March, 1918. The data for April to June, 1918, are at the printer's, and still more recent data are now nearly ready for the printer.

In its purpose to render the greatest possible assistance in the vigorous and successful prosecution of the war, the Weather Bureau has cooperated with various branches of the United States Army in the following ways:

1. Papers on "Meteorology and aeronautics," "Mean values of free-air barometric and vapor pressures, temperatures, and densities over the United States," and "The turning of winds with altitude" were prepared and published and copies have been furnished for the information and use of the aviation and artillery services.

2. Numerous requests have been made upon the Aerological Section of the Weather Bureau for specific information relative to atmospheric conditions in connection with aviation, artillery problems, and for other purposes, both in the United States and in Europe.

3. Instrumental equipment, including kite meteorographs, has been supplied for the use of the American Expeditionary Forces, the British Admiralty, etc. Assistance has been extended to the subcommittee on free-flight tests in supplying from the instrument shops of the Weather Bureau certain mounted clock movements for recording instruments needed in those tests, including the loan of a special pair of recording theodolites.

4. In connection with special experimental tests temporary field stations have been established and kite flights made at Ellington Field, Tex., Potomac Park, Washington, D. C., and Aberdeen Proving Grounds, Md.

In order to permit of flying kites without interference in aviation work it has been necessary to locate the aerological stations of the Weather Bureau elsewhere than in the immediate vicinity of aviation camps. In order, however, to provide for the local needs of aviation and other military requirements, cooperation with the meteorological section of the Signal Corps has resulted in the establishment of about 25 meteorological and pilot balloon stations at properly selected military camps. The work at these stations under military direction consists chiefly of observations of surface meteorological conditions, accompanied by theodolite observations of the flight of small rubber hydrogen-inflated pilot balloons. The observations with such balloons, when properly reduced, give the path of the balloon in the free air and thus reveal the general horizontal motions according to the altitude of the balloon. Under proper conditions of inflation the rate of ascent of the balloon is more or less accurately known, and the observations also afford some indication of the up-and-down motions in the atmosphere, as well as the horizontal motions, notwithstanding the steady ascent of the balloon.

Arrangements between the Science and Research Division of the Signal Corps and the Weather Bureau have been perfected, whereby a small group of men are engaged in reducing and computing the results of the measurements of pilot balloons, and it is planned in the near future to begin the distribution of systematic reports of the atmospheric motions obtained from these pilot balloons. To make this information immediately available, the observations from the balloons must be telegraphed, but this has not as yet been undertaken, and the results reported by mail are necessarily for conditions some days prior to the date of publication. It is believed that from observations of this character much useful information can be given concerning the free motions of the atmosphere in different sections of the country, and the stations have been located with a view to making this information most valuable in connection with cross-country flying along lines of civil aerial transport which have already been in a measure agreed upon.

The program of the subcommittee on the relation of the atmosphere to aeronautics is to continue lines of work already started and in operation. The most important of these are:

(*a*) *Aerological observations at Weather Bureau stations.*—Daily observations are made of free-air pressure, temperature, humidity, wind and cloud conditions at six favorably distributed stations. This work is conducted by the United States Weather Bureau under appropriations for that purpose. The stations are Broken Arrow, Okla., Drexel, Nebr., Ellendale, N. Dak., Groesbeck, Tex., Leesburg, Ga., and Royal Center, Ind.

(*b*) *Pilot-balloon observations at military stations.*—Daily observations are made of free-air wind conditions by means of small pilot balloons whose positions and motions are observed by theodolites. This investigation is conducted by the Science and Research Division, United States Signal Corps, at about 25 military training camps distributed over the United States from the Rocky Mountains to the Atlantic coast. In cooperation with the United States Weather Bureau, pilot-balloon soundings are made also at five of its aerological stations.

The objects of the work described above are as follows:

(1) To make the data obtained immediately available for the information and assistance of all interested therein, such as (*a*) meteorologists, (*b*) aviators at training fields and those engaged in cross-country flying over the transcontinental mail or other aerial routes, (*c*) the Army and Navy for artillery services, and (*d*) pilots over the proposed trans-Atlantic route from Newfoundland to Ireland or between other points.

(2) To summarize, study, and publish the data obtained for the purpose of furnishing reliable information as to average free-air conditions of pressure, temperature, humidity, density, and wind direction and velocity by months and seasons, under different types of pressure distribution at the earth's surface and in different parts of the country.

(3) To conduct special studies of atmospheric phenomena which are of particular interest to the aviator, as, for example, (*a*) air movements in thunderstorms, (*b*) height and thickness of cloud layers in different parts of low-pressure areas, (*c*) amount and vertical extent of convection, and (*d*) gustiness of winds.

(4) To encourage the fuller development of the systematic use of airplanes as an aerial apparatus auxiliary to kites and balloons, by means of which meteorological conditions in the free air may be observed and measured.

QUARTERS FOR COMMITTEE.

During the fiscal year ending June 30, 1918, the administrative offices of the National Advisory Committee for Aeronautics were located in rented quarters in the Munsey Building, Washington, D. C. The technical work of the committee, performed largely by or under the direction of the various subcommittees, was carried out in various laboratories and shops belonging to the Government and to universities of learning whose facilities for scientific research were placed at the disposal of the committee.

The sundry civil act making appropriations for the fiscal year 1919, approved July 1, 1918, contained the following provision in reference to quarters:

> *Provided*, That the Secretary of War is authorized and directed to furnish office space to the National Advisory Committee for Aeronautics in governmental buildings occupied by the Signal Corps.

In accordance with the above provision of law, the Bureau of Aircraft Production of the War Department allotted sufficient space to the committee in Building D, Fourth Street and Missouri Avenue NW., Washington, D. C., and this space was occupied by the committee on July 1, 1918. The location is the fourth wing, second floor, immediately adjoining the offices of the Director of the Air Service, Mr. John D. Ryan. It is believed that its present location between the Bureau of Aircraft Production and the Division of Military Aeronautics is most appropriate for the conduct of its own work and to aid in effecting close cooperation of effort on the part of the military agencies in matters under the cognizance of the committee.

THE RESEARCH LABORATORY.

The research laboratory located at Langley Field, Va., has been completed and equipped to undertake certain types of research work on aerodynamical problems and aeronautic instruments. Tests of the performance of airplanes in free flight will also be carried out at Langley Field.

The original purpose in the establishment of Langley Field by the War Department was to provide an experimental flying field and proving ground for aircraft. During the war the field was used primarily as a training school for aviators, but it is contemplated that after the war it will be fully developed in accordance with the original plan.

WIND TUNNEL.

As a part of the equipment for scientific research, the committee contracted for the construction of a wind-tunnel building on the same plot of ground allotted to the committee by the War Department for the conduct of its general activities at Langley Field.

The wind-tunnel building is of brick and steel construction, 42 feet wide, 90 feet long, and 30 feet high. It will house a 5-foot modified Eiffel type wind tunnel which has been designed to provide for lessening the diameter of the wind stream to 30 inches for high-velocity investigations. When operating with the 5-foot section, the air stream is left open across the operating room, and when operating with the 30-inch section, the stream is inclosed as in the National Physical Laboratory type of tunnel.

The wind tunnel proper will be equipped with a thrust torque dynamometer for propeller investigations and for determining the effect of the fuselage form upon propeller efficiency; also an aerodynamic balance for making accurate measurements on aerofoils. Both the balance and the dynamometer will be suspended from an overhead platform down into the wind stream. In each case the observer will work above the platform. Power will be supplied to the wind-tunnel propeller by a 250-horsepower, direct-current, variable-speed motor which will be operated by a 250-kilowatt synchronous motor generator set, with special arrangements for speed control and regulation.

The wind tunnel is designed for air velocities up to 130 miles per hour with the 5-foot section and for 200 or more miles per hour when using the 30-inch section. Important research problems will be undertaken as soon as the building and apparatus are completed.

As reported in the third annual report, it is contemplated that an additional wind-tunnel building and an engine-testing shed will be required in the near future.

OFFICE OF AERONAUTICAL INTELLIGENCE.

In January, 1918, the need for a central governmental depository in Washington for scientific and technical data relating to aeronautics was recognized, and the Aircraft Board suggested that the National Advisory Committee for Aeronautics was the logical governmental agency for the collection and classification of such data to be made available to the military and naval air services in this country. This committee accordingly established an Office of Aeronautical Intelligence and adopted rules and regulations for the handling of its work.

The committee has made the necessary arrangements at home and abroad for the collection of such data. There are many sources of obtaining such information, the chief at the present time being the research information committee, organized under the National Research Council in January, 1918, by funds provided by the Council of National Defense. It consisted of the Director of Military Intelligence, Director of Naval Intelligence, and Dr. S. W. Stratton as chairman.

The purpose of the research information committee is to serve as a collector and distributor of scientific and technical information regarding all war problems. Special committees stationed at London, Paris, and Rome collect information regarding all phases of the scientific and technical study of war problems and transmit the same to the central committee in Washington for distribution to the interested services. Similarly, these special committees receive information from Washington and transmit the same to the interested services abroad.

Since February, 1918, Dr. W. F. Durand, chairman of the National Advisory Committee for Aeronautics, has served as scientific attaché to the American Embassy in Paris, representing the National Research Council on this research information service, and has, in addition, acted as special representative of the Aircraft Board at the International Aircraft Standardization Conferences in London in February and in October, 1918, besides serving as a special liaison officer in aeronautical matters between France and the United States.

In September, 1918, Dr. W. C. Sabine, head of the department of technical information of the Bureau of Aircraft Production and a member of the National Advisory Committee for Aeronautics, was placed in charge of the Office of Aeronautical Intelligence of the National Advisory Committee for Aeronautics, with the title of director of scientific and technical data.

Many valuable documents dealing with important research problems in aeronautics have been secured by the Office of Aeronautical Intelligence, and copies have been distributed to those concerned with the problems involved.

The committee has established in connection with its Office of Aeronautical Intelligence, and particularly for the use of its engineering staff, a small selected library, containing the most useful and valuable aeronautical and technical books and publications.

THE COMMITTEE AS AN IMPARTIAL AGENCY FOR THE SETTLEMENT OF DISPUTES.

During the past year the committee has served the War and Navy Departments in the capacity of an impartial agency for the settlement of disputes between contractors or private parties on the one hand and the War or Navy Department on the other in matters where technical questions have been involved. In each case in which it has been requested to act the committee has appointed a special subcommittee to investigate and submit report and recommendation. The more prominent cases handled by the committee during the past year are:

First, the dispute between the War and Navy Departments on the one hand and the Kessler Motor Co. relative to the degree of compliance by the latter with the technical provisions of a contract for the development of experimental aircraft engines.

Second, the controversy between the War Department and George Norman Albree et al. over the merits of the Albree monoplane.

Third, the case of the contract with the Glenn L. Martin Co. for a large bombing plane with a smaller pilot plane fastened to it in such a manner as to automatically control the larger plane and direct its course after the small pilot plane has been released, the larger plane to carry and automatically release a large bomb of the type invented by Lester P. Barlow, upon whose suggestion the experiments were made. A contract had already been completed, entailing the expenditure of $15,000, and a controversy arose over the advisability of placing a further contract involving $150,000. In this case the committee, after careful consideration, recommended that contract be not placed, since the military value of the machine did not justify its use.

AIRCRAFT PRODUCTION.

During the past year the National Advisory Committee for Aeronautics has not undertaken to function on the problems connected with aircraft production nor in the framing of the aircraft program. These matters have been under the jurisdiction of the War and Navy Departments, respectively, and their problems have been coordinated in an advisory capacity, first, by the Aircraft Production Board and later by the Aircraft Board.

THE CLARKE THOMSON RESEARCH.

The Clarke Thomson Research was founded by Mr. Clarke Thomson of Philadelphia, Pa., on September 23, 1916, for the purpose of aiding the advancement of the science of aviation.

In the latter part of the year 1917, Mr. Thomson tendered the facilities of the Clarke Thomson Research to the National Advisory Committee for Aeronautics with the request that the National Advisory Committee direct the further activities of the research:

The activities of the research previous to that time may be summarized as follows:

1. A research on the possibilities of the steam power plant for aeronautical purposes, the results being published in a report "Steam-power plants for airplanes," by J. G. Dudley.

2. The investigation of the possibilities of the gas turbine as a power plant for airplanes. Inherent difficulties involved in the construction of the gas turbine seemed to eliminate this device as a power plant for airplanes.

The first problem presented to the research by the advisory committee was the application of the Nutting 2-cycle air-scavenging principle to some existing engine, in order to test and determine the possibilities of this particular type of engine. The research redesigned and reconstructed a Dusenberg 4-cylinder 16-valve aircraft engine to operate on the Nutting 2-cycle air-scavenging principle. After construction, this engine was tested by the power plants committee at the Bureau of Standards. The results of the experiment indicated that the inherent difficulties were too great to justify continuation of the development when the more important problems requiring prompt solution were considered. It is planned to resume this investigation in the near future, as the possible results are of great interest.

In connection with the problem involving exhaust-gas scavenging, the research conducted experiments of the flow of air through poppet valves. A model on a Liberty engine cylinder was constructed, and experimental data dealing particularly with the merits of inlet valves, singly and in pairs, was obtained. The result of this experimental work is found in Report No. 24 of the National Advisory Committee for Aeronautics, entitled "Air flow through poppet valves."

SCIENCE AND RESEARCH DIVISION.

In the latter part of the year 1918 the committee stated in a letter to the Director of the Air Service of the Army that there was need for greater coordination of the scientific and research work in aeronautics, and that in order to render effective the work of the division of science and research, established by the Signal Corps and later transferred to the Bureau of Aircraft Production, it was believed desirable to reorganize the division of science and research.

The committee recommended that that portion of the work of the Bureau of Aircraft Production and of the Division of Military Aeronautics, which was then under the direction of the division of science and research of the Bureau of Aircraft Production, be organized under a separate division under the Bureau of Aircraft Production, with a director in charge whose entire interests were connected with and who could give his entire time to the work of the Air Service of the Army. The effect of this was a separation of the science and research work of the Air Service from the science and research work of the Signal Corps.

AIR MAIL SERVICE.

In March, 1918, the committee invited the attention of the Secretary of War to the fact that Congress had authorized the Post Office Department to establish an experimental air mail service and had made an appropriation of $100,000 for the purpose, and that under the then existing conditions practically all aircraft manufacturing facilities in the United States were being utilized by the War and Navy Departments, and all capable aviators were in the military or naval air services.

The committee also stated that in view of the further fact that it was exceedingly desirable that Army aviators be regularly and systematically trained in long-distance flying, it would appear to be to the advantage of the War Department and of the Government generally that military airplanes and aviators be used to render practical and effective service to the Nation by assisting the Post Office Department, and recommended that active cooperation be estabished between the Air Service of the Army and the Post Office Department in connection with the proposed experimental air mail service between Washington, Philadelphia, and New York.

The air mail service was successfully inaugurated, with the cooperation of the War Department, and in the opinion of the National Advisory Committee for Aeronautics the practicability of such service has been sufficiently well demonstrated since its inauguration to justify its extension generally.

CIVIL AERIAL TRANSPORT.

With the cessation of hostilities, the committee promptly took up questions relating to civil and commercial uses of aircraft after the war. The great developments in and achievements with aircraft during the past few years, due to the stimulation of war, indicate that the civil and commercial uses of aircraft in the future may be considered to be practically unlimited.

The committee believes that Federal legislation should be enacted governing the navigation of aircraft in the United States and including the licensing of pilots, inspection of machines, uses of landing fields, etc. The committee has brought this subject to the attention of the heads of the War, Navy, Commerce, and Post Office Departments, and suggested that representatives be appointed to confer with the committee with a view to studying the problem and recommending the general terms of legislation designed to most effectively encourage the development of aviation in the United States, and at the same time to guide the development as far as practicable along such lines as will render immediate and effective military service to the Nation in time of war.

ELECTROMAGNETIC SYNCHRONIZER FOR AERONAUTICAL MACHINE GUNS.

An investigation of the subject of synchronizing gears for machine guns to be used in connection with airplanes has been carried on in conjunction with the staff of the Bureau of Standards; and an electromagnetic synchronizing gear has been evolved which will perform all the functions of the hydraulic and mechanical gears and with an efficiency fully as great. It has certain marked advantages, such as flexibility of mounting. This will enable the machine gun to be traversed on a horizontal plane, while at the same time being maintained in perfect synchronism.

VENEER WING CONSTRUCTION.

Sand loading and other tests made by members of the committee's technical staff on an experimental airplane built by the Carolina Aircraft Co. revealed the utility of wood veneer in wing construction, not only for ribs but also for the actual wing covering. It was found that the internal drift wires may be eliminated and the same weight per square foot of surface obtained as in the ordinary wing. The matter was reported promptly to the Bureau of Aircraft Production and attention invited to this method of wing construction as offering a possible means of cheaper and more rapid production of aircraft.

AIRPLANE MAPPING CAMERA.

Through the direct efforts of the airplane mapping committee, a triple lens airplane mapping camera was developed which was brought promptly and personally to the attention of the proper Army and Navy officers, and the camera itself turned over to the Geological Survey at its request. In the hands of the officials of this survey it has already proved to be of inestimable value in making topographical surveys.

AIRCRAFT-ENGINE FUELS.

During the past year Mr. A. J. Paris, jr., of Charleston, W. Va., tendered to the committee his services as an inventor and the use of his experimental station at Charleston, consisting of a gas-engine-driven gas-compressing plant, miniature oil refinery and laboratory for investigation of aircraft-engine fuels. On recommendation of the committee and by order of The Adjutant General of the Army, his brother, First Lieut. W. F. Paris, 102d Trains and M. P., 27th Div., U. S. A., was detailed with the committee and was assigned to assist with this problem.

Research and experiment have been conducted by Messrs. Paris at Charleston, in full cooperation with, and under the direction of the National Advisory Committee for Aeronautics, the expenses being borne by them. The subjects investigated during the past year are as follows:

1. Gasoline direct from crude petroleum without stills; cleaned without use of acid or alkali.

2. First distillate or crude benzine, cleaned, and purified without the use of acid or alkali.
3. Natural neutral gasoline.
4. Increased yield of straight paraffin gasoline from crude oil.
5. Separation of gasoline from crude oil by mechanical means.

Quality samples of pure paraffin gasoline from crude oil were completed and delivered in July, 1918, and these were referred to the subcommittee on power plants for test at the Bureau of Standards. The object of these investigations has been to produce a superior product and at the same time increase the proportionate yield of this superior grade of gasoline for aircraft and also reduce the cost of production. This work is described in detail in Report No. 42, showing the nature of the tests and the degree of success achieved.

EVOLUTION OF AIRCRAFT ENGINES.

The first man-carrying-airplane flights were made in December, 1903, with the Wright Brothers' engine, developing 12 horsepower and weighing 152 pounds, or 12.7 pounds per horsepower. In 1910, seven years later, the average horsepower of aeronautic engines had increased to 54 and the weight decreased to 5.7 pounds per horsepower. In another seven years, 1917, the average power output had advanced to 240 horsepower and the weight lowered to 2.8 pounds per horsepower. At the end of 1917 the Liberty-12 developed 400 horsepower for a weight of 800 pounds or 2 pounds per horsepower. Continuous progress in development enabled the Liberty-12 to yield a maximum of 510 horsepower for a weight of 875 pounds, or 1.71 pounds per horsepower, by the end of August, 1918.

The accompanying table, as also the curve sheet, shows the advance in the average maximum power-weight ratio by years for the engine in actual flying service. It is to be especially noted that the Langley-Manly engine was 9 years ahead of its time in the matter of power output and 16 years ahead in weight per horsepower ratio.

It may also be noted that at the end of 1917 the Liberty-12 was 65 per cent more powerful and 28 per cent lighter per horsepower than the average in service for that year. By September 1, 1918, these figures were changed to approximately 50 per cent and 25 per cent, which indicate the superiority of the Liberty-12 over the average engine in service at that time.

Aircraft-engine evolution.

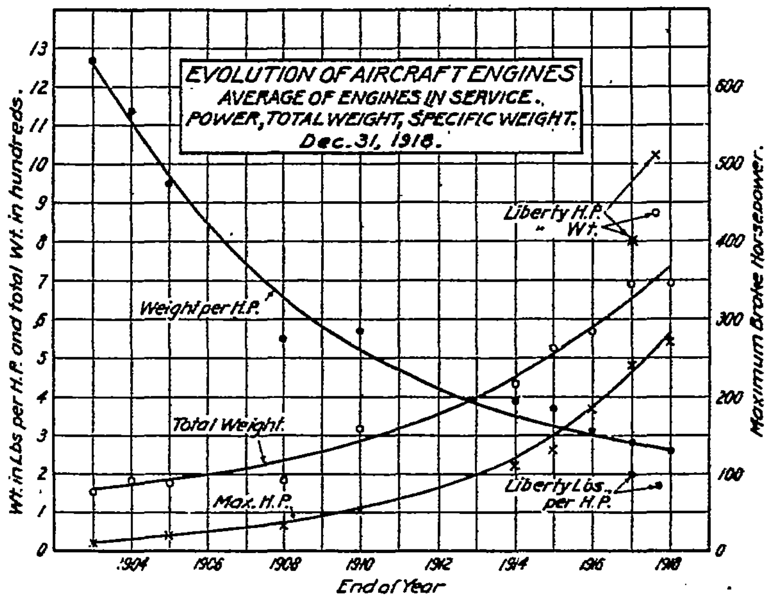
Type.	Year.	Horsepower.	Weight.	Weight per horsepower.
Langley-Manly engine	1901	52	151	2.9
Original Wright Bros	1903	12	152	12.7
Improved Wright Bros	1904	16	180	11.4
Do.	1905	19	180	9.5
Redesigned Wright Bros	1908	35	182	5.5
Average in service	1910	54	309	5.7
Do.	1914	112	437	3.9
Do.	1915	133	512	3.7
Do.	1916	185	570	3.1
Do.	1917	243	693	2.8
Liberty, 12-cylinder	1917	400	801	2.0
Average in service	1918	267	693	2.6
Liberty, 12-cylinder	1918	510	875	1.7

The average consumption of fuel decreased from about 0.80 pound per horsepower in 1903 to about 0.65 pound in 1914, since which it has slowly dropped to 0.55 pound in 1918, and, for the Liberty, to 0.50 pound. The present minimum Liberty consumption is approximately 0.46 pound per horsepower hour.

The lines on the curve sheet show the average values obtained for these several variables during the same period as is covered by the table. The points indicated by small circles represent the characteristics of the Liberty-12. Note particularly the lower weight per horsepower as compared with the curve showing average practice. As further illustrating the advance made, it is interesting to note that in 1913, the Wolseley company could only obtain 147 horsepower at 1,400 revolutions per minute from eight cylinders, 5 inches bore by 7 inches stroke, or 18.375 horsepower per cylinder. This is the same cylinder size as used in the Liberty, which now gives

42.5 horsepower per cylinder, 2.3 times the power per cylinder obtained in the Wolseley. Even if we reduce the Liberty results to the same speed as the Wolseley, 1,400 revolutions, the Liberty still represents a marvelous advance, for at that speed 378 horsepower are developed, or 31.5 horsepower per cylinder. Moreover, the Wolseley weighed 4.9 pounds per horsepower as compared with 2.3 pounds for the Liberty at the same speed.

Regarding future accomplishments, the tendency of the curve showing the weight per horsepower is such as to indicate that the average of aeronautic engines will not attain the present high power weight ratio of the Liberty-12 until some time in 1921, which would indicate that the Liberty may be supposed to be two years in advance of the state of the art.



AERONAUTICAL INVENTIONS.

During the past year, this committee has handled approximately 7,000 inventions and suggestions in the field of aeronautics. A great many of these have been referred to this committee by other departments of the Government, such as the Bureau of Standards, the Aircraft Board, and the War and Navy Departments.

The inventions received have been of the following nature: Lighter-than-air craft (balloons and dirigibles); heavier-than-air craft (ornithopters, helicopters, airplanes); motive power; propellers; offensive devices.

Under the subject of airplanes there have been numerous suggestions relative to improvements in the various details, such as controls, fabric, instruments, parachutes, stabillizers, wings, coloring, and fireproofing solutions.

Under the subject of motive power there have been many suggestions relative to steam and combustion engines, and various improvements to the latter.

Under the subject of combustion engines, there have been many suggestions and inventions relative to both fixed and rotary engines and turbines; and under engine parts suggestions relating to mufflers, carburetors, ignition, fuel tanks, starters, radiators, valves, etc.

Numerous suggestions have been received having to do with various forms of air propellers, both fixed and variable pitch, and constructed of both wood and metals.

Another field for the inventor is that of offensive devices for use in connection with aircraft. Under this heading the committee has received suggestions relative to both incendiary and explosive bombs, together with means for dropping them; also chemicals and other forms of offensive devices.

The great majority of the suggestions and inventions received are obviously of an impractical nature. Several, however, have seemed worthy of further consideration and have been referred to military or naval experts. Such matters have been followed up and specific reports obtained in each case. The inventor is invariably thanked for his patriotism in submitting his device for the use of the Government.

In addition, a large number of suggestions and inventions of minor importance have been recommended to the War and Navy Departments for their further consideration. In all cases, every invention and suggestion has received immediate attention.

A small percentage of the inventions have been deemed worthy of serious action after having been carefully considered. These are listed below:

1. Instrument to prevent excess transverse stresses in an airplane engine. This was given full trials at McCook Field, and at the navy yard, Washington, D. C.
2. Multitandem triplane system of aerofoil arrangement. This arrangement was designed to enable the carrying of great loads without great increase in the wing span. It was thought necessary to make wind tunnel tests upon the basic principle involved. These have been conducted at the navy yard wind tunnel.
3. A two-cycle air scavenged internal combustion engine. This was carefully investigated and experimented upon, but was not found suitable for the immediate needs of military aeronautics.
4. A magneto having the well-known Bosch characteristics but with several ingenious improvements in mechanical design was submitted to careful laboratory tests. The manufacturer is building a supply for service tests.
5. A design of variable camber steel rib intended to serve as part of one of the wings of a biplane or triplane with the remaining wings of fixed camber. The use of such a device will materially increase the speed range of an airplane. Extensive tests of a mechanical nature have been carried out on this construction with very hopeful results.

In July, 1918, the War Department established an inventions section of the General Staff and issued instructions to all branches of the War Department to forward all inventions including those pertaining to aeronautics to the inventions section. This action has served to relieve the committee of the duty of preliminary examination of a large number of inventions and suggestions without value. Cooperation with the inventions section has been established, whereby all inventions dealing with aeronautical subjects which, after preliminary examination, are deemed by the inventions section worthy of further consideration are referred to this committee. Other departments of the Government, however, have continued referring aeronautical inventions and suggestions to this committee direct.

TECHNICAL REPORTS.

The first annual report of the committee contained technical reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23. With this, the fourth annual report, the committee submits technical reports Nos. 24 to 50, as follows:

Report No. 24, entitled "Air Flow through Poppet Valves," was prepared by the Clarke Thomson Research and contains the results of investigations made by G. W. Lewis and E. M. Nutting, of the Clarke Thomson Research. Some of the new ideas to which attention is called in this report have already proved of great value in the gas-engine industry.

Report No. 25, entitled "Nomenclature for Aeronautics," is a glossary of words used in connection with aeronautics, adopted by this committee in October, 1918. This nomenclature has also been adopted by the War and Navy Departments. It was prepared in cooperation with a committee engaged upon a similar undertaking in Great Britain. As a result this nomenclature is in substantial agreement to the one which has been adopted by the aeronautical authorities of Great Britain.

Report No. 26, entitled "The Variation of Yawing Moment Due to Rolling," by Prof. E. B. Wilson, of the Massachusetts Institute of Technology, is a contribution to the study of airplane stability concerning a point about which much discussion has arisen.

Report No. 27, entitled "Theory of an Airplane Encountering Gusts, III," by Prof. E. B. Wilson, of the Massachusetts Institute of Technology, is the third of a series of papers on this subject, the two previous papers having appeared in the first and third annual reports of the committee.

Report No. 28, entitled "An Introduction to the Study of the Laws of Air Resistance of Aerofoils," by Dr. George de Bothezat, of the technical staff of this committee, is a memoir dealing with the flow of air around aerofoils and the laws which may be deduced mathematically for this condition. Numerous new ideas are evolved, and the author has made great progress over the existing knowledge of the subject.

Report No. 29, entitled "The General Theory of Blade Screws," by Dr. George de Bothezat, of the technical staff of this committee, gives an entirely new treatment of the theory of the principles governing the action of a screw consisting of blades, such as we have in propellers, fans, etc. This theory is developed extensively. The methods are described with careful drawings, so that one should be able to design propellers for any specific purpose. This contribution to the science of aerodynamics is most notable.

Report No. 30, entitled "Experimental Research on Air Propellers, II," by Dr. W. F. Durand and Prof. E. P. Lesley, is a continuation of Report No. 14 on the same subject published in the third annual report of this committee, and has been prepared by Prof. E. P. Lesley, of Leland Stanford, jr., University. It states the results of investigations made upon numerous propeller models at request of this committee and affords valuable data to those interested in the design of air propellers.

Report No. 31, entitled "Development of Air Speed Nozzles," by Dr. A. F. Zahm, of the department of construction and repair, navy yard, Washington, D. C., a member of the subcommittee on navigation of aircraft, aeronautic instruments and accessories.

Report No. 32, entitled "The Airplane Tensiometer," by L. J. Larson, of the Bureau of Standards, describes a new instrument for the purpose of measuring the tension in airplane wires and cables.

Report No. 33, entitled "Luminous Materials," by Dr. N. E. Dorsey, of the Bureau of Standards, gives for the first time, in complete form, all the data necessary for the specifications of luminous materials in connection with various instruments, especially those used for aeronautics.

Report No. 34, entitled "Aluminum and Its Light Alloys," by Dr. Paul D. Merica, of the Bureau of Standards, is a summary of the publications by the Bureau of Standards on this subject during the past year.

Report No. 35, entitled "The Strength of One-piece, Solid, Built-up, and Laminated Wood Airplane Wing Beams," by John H. Nelson, of the Bureau of Standards, describes an experimental investigation on the relative strengths of beams when solid, built-up, and laminated. This report has already proved of great value in the airplane industry inasmuch as the results have been widely disseminated.

Report No. 36, entitled "The Structure of Airplane Fabrics," by E. D. Walen, of the Bureau of Standards, is a most complete discussion of the methods used and the results obtained in testing linen, silk, and cotton fabrics. The results of this investigation have been made known from time to time to the military authorities of both services, and the great progress made in the United States during the past year in the production of airplane fabrics is directly due to the success obtained in securing proper cotton fabrics as described in this report.

Report No. 37, entitled "Fabric Fastenings," by E. D. Walen and R. T. Fisher, of the Bureau of Standards, states the results of a careful investigation upon the proper methods of attaching fabrics to airplane wings. The methods recommended in this report have been adopted by the military services.

Report No. 38, entitled "Airplane Dopes and Doping," by W. H. Smith, of the Bureau of Standards, is a most valuable statement of the difficulties in the preparation of dopes and of the means which have been taken to overcome them.

Report No. 39, entitled "The Testing of Balloon Fabrics," prepared by Junius David Edwards and Irwin L. Moore, of the Bureau of Standards, deals with the various methods by which balloon fabrics may be tested and gives a critical discussion of the relative values of these tests from a practical standpoint.

Report No. 40, entitled "The Ferrosilicon Process for the Generation of Hydrogen," is a series of three papers prepared by the staff of the Bureau of Standards. Their titles and authors are as follows: "Generation of hydrogen from ferrosilicon and sodium hydroxide," by E. R.

Weaver, W. M. Berry, and V. L. Bohnson; "The effect of the presence of sodium carbonate on the generation of hydrogen from ferrosilicon and sodium hydroxide," by E. R. Weaver and B. D. Gordon; "The use of lime in the generation of hydrogen by the use of ferrosilicon," by B. D. Gordon. This report gives a valuable summary of the details of the ferrosilicon process and a critical examination of the means which are necessary in order to make the process successful.

Report No. 41, entitled "Testing of Balloon Gas," by Junius David Edwards, of the Bureau of Standards, is a description of a simple, portable apparatus for testing hydrogen, with special reference to its use in balloons.

Report No. 42, entitled "A New Process for the Production of Aircraft Engine Fuels," by Auguste Jean Paris, jr., and W. Francklyn Paris, first lieutenant, United States Army, states the results of investigations performed by its authors at the request of this committee at their laboratory at Charleston, W. Va.

Report No. 43, entitled "Synopsis of Aeronautic Radiator Investigations for the years 1917 and 1918," by Dr. H. C. Dickinson and R. V. Kleinschmidt, gives the results of investigations conducted at the Bureau of Standards on the general problem of aeronautic radiator design.

Report No. 44, entitled "The Altitude Laboratory for the Testing of Aircraft Engines," by Dr. H. C. Dickinson and H. T. Boutel, is an extension and revision of the brief description of this apparatus which appeared in the third annual report. The changes which have been made as a result of experience have been included so that this report describes the laboratory in its developed form.

Report No. 45, entitled "The Effect of Compression Ratio, Pressure, Temperature, and Humidity on Power," in four parts, by Dr. H. C. Dickinson, W. S. James, G. V. Anderson, and V. W. Brinkerhoff, gives the results obtained in testing a Hispano-Suiza 150-horsepower aircraft engine in the altitude chamber, and of a high-compression truck engine on the dynamometer stand at the Bureau of Standards. The results of pressure and compression ratio changes agree very closely with the ordinary conception, but it is interesting to note the indication of the tests with respect to the deviation of the temperature correction from that ordinarily assumed. The water-injection tests are an indication of the value of such devices and of the effect of changes in humidity.

Report No. 46, entitled "A Study of Airplane Engine Tests," by Prof. Victor R. Gage, gives the results of an examination of the data obtained during tests of aeronautic engines in the altitude laboratory at the Bureau of Standards.

Report No. 47, entitled "Power Characteristics of Fuels for Aircraft Engines," in three parts, by Dr. H. C. Dickinson, W. S. James, E. W. Roberts, Prof. V. R. Gage, and D. R. Harper, 3d, presents a summation of the results obtained in the testing of fuels of various compositions and character in the altitude laboratory. These tests extended over several months and thousands of readings were taken. The data upon which this report is based is of the greatest value and has had an extremely important influence upon the writing of specifications for the various grades of aviation fuels.

Report No. 48, entitled "Carbureting Conditions Characteristic of Aircraft Engines," by P. S. Tice, was prepared as a digest of the information obtained during an extensive examination of the performance of aircraft engines in the altitude laboratory at the Bureau of Standards. It constitutes a concise statement of the difficulties to be encountered in this branch of carburetion.

Report No. 49, entitled "Metering Characteristics of Carburetors," by P. S. Tice and Dr. H. C. Dickinson, is mainly the result of an extensive experimental investigation of the performance of different types of carburetors as effecting the maintenance under all conditions of a correct ratio between the weights of fuel and air.

Report No. 50, entitled "Calculation of Low Pressure Indicator Diagrams," by E. C. Kemble, develops the fundamental conception and partial application of a method for calculating the pressure-volume relationships to be expected for any given engine design.

GENERAL PROBLEMS AND ACTIVITIES.

As an introduction to the progress made on the general problems enumerated in the preceding annual reports, there is submitted the following statement entitled "Some Outstanding Problems in Aeronautics," prepared by Dr. W. F. Durand, chairman of the National Advisory Committee for Aeronautics, which was read as the Sixth Wilbur Wright Memorial Lecture before the Aeronautical Society of Great Britain on June 25, 1918:

SOME OUTSTANDING PROBLEMS IN AERONAUTICS.

Ten years ago the airplane was a curiosity—a means wherewith, by a tour de force, a man might lift himself from the ground and make a hazardous flight through quiet air—a means to attract curious crowds to fenced-in country fairgrounds to witness the marvel of a body heavier than air actually rising from the ground and moving under some measure of control through the air, and returning safely to its starting point.

What the airplane has become in this short but poignant decade of the world's history and what it stands for to-day this audience knows too well to need specification in detail.

It is perhaps well within the limits of conservatism to say that no achievement of man's inventive and constructive genius has undergone more intensive, more rapid, or more potentially significant development than has that of flying with an apparatus heavier than the air in which it moves.

It may be further noted that perhaps no technical and constructive achievement of man has ever called more largely on science and on the aid of scientific research to aid in the solution of the many problems which have presented themselves in the course of this astonishing development in aerial navigation which the past decade has witnessed.

In the circumstances which have determined the direction and character of the development of the airplane during this decade, and especially in those which have been controlling during the past three or four years, it is only to be expected that at the present moment we should find ourselves with many partly solved problems on our hands, with others which we have hardly more than begun to attack on the outskirt, and confronted by others still, the charac acter and significance of which we have hardly begun as yet to apprehend.

On the present occasion we may find it not without interest to pass briefly in review some of these problems, noting their present status together with such indications as may in some cases serve to point the way toward a possible solution.

THE PROBLEM OF CONSTRUCTIVE MATERIALS.

Perhaps nowhere is there to be found a better illustration of the interdependence of technical and scientific research and study than in the manifold advances in various technical and scientific lines which conjointly have made the airplane in its present form a structural possibility.

Broadly, the modern airplane comprises a body of some sort or form fitted with wings to provide the supporting surfaces, with a prime mover or source of power and with a propeller of some type to transform the power provided by the prime mover into propulsive work, and by the reaction of the relative air stream on the under side of the wings to secure the sustaining or lifting force necessary to carry the weight. This construction calls for a wide range of constructive materials. Thus the body and wings, comprising the airplane proper, require the following fairly distinct classes of structural elements:

(1) Those intended primarily to give form, strength, and coherence to the structure. They represent in effect the skeleton or foundation on which the entire function of the airplane as such must depend.

(2) Various secondary elements intended so to tie or connect the principal members together as to secure homogeneity of structure as a whole, and mutually responsive action on the part of the different elements comprised under No. 1. The elements here considered are those which, from a purely structural viewpoint, may be classed as struts and ties or tension members.

(3) Surface covering for the body and wings. This gives outer form and continuity of surface and provides, furthermore, the actual surfaces on which the air lifting and supporting forces may act.

Broadly speaking, the fundamental problem in all airplane construction is adequate strength or function on minimum weight. In no other form of engineering construction is the necessity for weight saving so rigorous. In a very real sense every ounce of material entering into the structure must be able to show a competent passport. The structural problem of the airplane is therefore one of strength in relation to weight. For the main elements comprising the skeleton of the structure wood has, thus far, held the main place, with metal construction steadily attracting more and more interest and assuming a place of growing importance, at least in the study of new designs.

It is not necessary to our present purpose that we should consider in detail present practice in airplane construction. The trend of development since the earliest days of the art has tended to show that wood construction under suitable design and safeguard was able to provide the easiest and, on the whole, the most satisfactory solution of many problems and requirements which airplane construction presents, and so we have been content, for the most part, with this type of construction.

We may, however, be well assured that however good may be any solution that we may reach of the many problems presented to us in the industrial arts, there are, as a matter of fact, series of better ones only awaiting our patient study. This is indeed a fundamental truth of which we should never lose sight. We may be, for the moment, satisfied with our solution of a problem in technical industry; we may be able to see nothing better, and yet we may be well assured that, as a simple matter of fact, there is something better. This is a perfectly safe assertion, if only as based on the law of probability of our having, at any given time, reached the final optimum possible combination capable of furnishing a solution of the problem.

Thus, as applied to the problem of constructing the framework of the fuselage of an airplane or of combining together wing spars and ribs in such a manner as to form a wing skeleton, we may be sure, however good our present practice may be and however satisfactory it may seem, that in reality it is not the best, and that long series of better solutions only await our intelligent and patient study.

In this and in all such problems there are always two fairly distinct though interrelated parts:

(a) What materials are best suited to the purpose in view.

(b) What disposition shall be made of the materials adopted.

Thus, in the case of the fuselage, granting wood material be adopted, there remains the question as to the very best distribution of such material as between the main longitudinal elements, or longerons, and the intermediate elements; also as to the extent to which reliance may be placed on the outer covering, especially if of plywood. What airplane designer can feel sure that, even with given materials, he has reached the optimum distribution of function as between the main and secondary elements of the fuselage and of a plywood outer covering.

Much less, what airplane designer can feel any confidence in having now reached an optimum combination, once we admit the possibility of metal construction or of some combination of metal and wood, with all the possibilities of the new light metal alloys and of the new alloy steels with their astonishing physical characteristics?

So far as conditioned by the application of the ordinary loading tests, static in character, and aside from the possible results of dynamic attack, shock, long-continued vibration, etc., we may perhaps frankly admit that the present state of metallurgy is able to supply us with material, either in the way of light aluminum alloys or special steel alloys, which, if properly used, will enable us to meet all such static tests in airplane construction, and on even terms or better as regards weight compared with wood.

If such is the case, it certainly stands before us as a problem for the near future to pass in review most thoroughly the entire range of constructive materials, metallic as well as wood, and to determine, in the light of the experience which we are so rapidly accumulating during these days of storm and stress in military aeronautics, the combinations of materials which may serve to give the most efficient service on the minimum of weight.

In connection with this search for new and better materials must go hand in hand search for better modes of combination in the structure—in other words, better structural design. It goes without saying that the best general type of design, in the way of the distribution of materials, forms and proportions of members, etc., will vary with the class of material employed. There must be some optimum design with wood. There will likewise be another and undoubtedly a different optimum design in the case of steel, and again different in the case of aluminum or other alloys. Thus the search for the best final combination is a search for an optimum optimorum; for the best possible material and for the best possible design using such material.

What order of saving may be looked for in the near future from any such search it is, of course, idle to predict. Could we, however, approach somewhat closely to the best use of the best combination of materials even now available in the field of engineering construction and without waiting for new and superior materials which the metallurgical art will doubtless be able to furnish, it seems not unreasonable to anticipate the possibility of a marked saving in weight without loss in strength or security.

This, then, stands out as one of the great problems of aeronautical engineering—that of the best materials and of their best use. Much has already been done, but much yet remains, and rich rewards most assuredly await patient and well-directed work in this field.

THE PROBLEM OF SIZE.

One of the most interesting of the problems presented to the aeronautical engineer is that of the limiting size and carrying capacity of airplanes. Is there such a limit? If so, what is it? Why is it? And how may it be removed or extended?

In dealing with this problem we come, of necessity, into contact with the laws of similitude of geometrically similar structures. It is well known that under simple modes of loading geometrically similar structures of wing and fuselage will have similar factors of safety under equal unit loads. But for such structures, if strictly similar geometrically, the weights themselves will increase as the cubes of the similar dimensions, while the areas of wing or supporting surfaces will only increase as the square, and hence the ratio of weight to area will continuously increase as the linear dimension.

In these circumstances it is readily shown that in accordance with the relation of the factors involved there will be, for any given speed, some size for which the lifting capacity over and above the structure itself will be a maximum and above which the lifting capacity over and above the structure will become less and less with increase in size, gradually reaching zero for some value of the size of the structure. This would mean that at such point the supporting force developed at the speed in question would be just enough to lift the structure itself from the ground but with no reserve for additional load.

This is, of course, a definite law derived from well-known principles of geometry and calculus, and if it were the whole story it would indeed tend to raise an insuperable bar before continued expansion in size. If such were the case, it would mean in effect that increase in lifting capacity could only be reached by the following measures:

(1) Reducing to a minimum the relation of weight of structure to area. That is, general improvement in the program of design and reduction of weight of structure in relation to supporting surface.

(2) Reducing to a minimum the resistance of the plane at the given speed and likewise the relation of weight to horsepower.

(3) Raising to a maximum the relation of lifting force to area, consistent, however, with the decrease of the total propulsive resistance of the plane.

Were we indeed subject, without recourse, to the operation of this law of mechanics and geometry, we should be in a sorry state regarding the future development of the airplane as regards size and carrying capacity. We should be limited strictly within the bounds of the developments made possible by improvements and advances along the lines as indicated above. But, fortunately for the future of aerial navigation, we are not so limited, and there seems no reason why, at the present time at least, we should need to anticipate any special limit as necessarily imposed on airplane construction as regards either size or carrying capacity.

We are able to escape from the consequence of this law due to two facts:

(1) It is not necessary that a large element of an airplane, a wing in particular, should be geometrically similar in structural characteristics to a small one. For a certain size the structural elements will partake of certain characteristics. As the over-all size increases, these elements may take on new characteristics. Those which had been solid may now become hollow or of lattice or built-up form. The law of geometrical similitude will not hold and the weight will not necessarily increase in ratio with the cube of the over-all linear dimensions.

(2) It is by no means necessary that a large airplane shall be, in its general form, a geometrical copy of a small one. While both will have similar elements, such elements need not be the same in number or arrangement. In fact, one of the most obvious of means for increasing lifting power is to increase the number of the wings or lifting elements. There is no reason, at least structurally, why wings and connecting elements should not be increased in number beyond anything now in use or even considered—increased to a point which would give a size and lifting power great enough to meet any demands which we can now formulate or which the future seems likely to present.

Structurally, therefore, the problem of increased size presents three problems, as follows:

(1) The structural problem of so developing the character of the elements of airplane construction, such as wing spars, longerons, struts, ribs, etc., that with increase in over-all dimension the weight shall not increase sensibly faster than as the square of such dimension.

(2) The structural problem of combining the larger elements of airplane construction, such as wings, fuselages, or engine nacelles, with their connecting structures, in such manner as to secure for a given wing area the minimum weight of secondary structure.

(3) The aerodynamic problem of combining multiple wing elements in such manner as to reduce to a minimum the interference of one with another. This is a problem which opens fascinating possibilities to the student of experimental aerodynamics—a problem on which already some beginnings have been made but one far from a final or as yet wholly satisfactory solution and one on which the future development of greatly increased size and carrying capacity seems destined to largely depend.

In short, then, so far as increase in size is concerned, there seems no reason to apprehend any particular limit or any serious difficulty on the part of the scientist and the engineer in meeting the demands of the future in these respects. The difficulties seem no greater than those which have been overcome in the case of ocean shipping as shown by the continuous development from the early beginning of the application of engine power to ocean navigation during the first half of the last century down to the mammoth floating structures of the present time; and if we may take any indication from the accelerated rate of progress which has characterized the entire history of aerial navigation, we may feel confident that we shall not have to wait a half or three-quarters of a century for a parallel development in the latter field.

VARIABLE WING AREA OF VARIABLE WING CAMBER.

To mention only one of the many remaining problems which are connected with the design and construction of the airplane itself, a word may be said with regard to the problem of variable wing area. Broadly speaking, the ideal airplane should be able to change its wing area in accordance with the conditions and circumstances of flight. For ease in getting off the ground at a moderate speed, for ease in landing likewise at a moderate or low speed, there is need of a relatively large area of wing or supporting surface. For the attainment of high speed, reduced wing areas are needed, and are, furthermore, sufficient for the support of the weight at such high speeds. The supporting force gained by a given form of airplane wing depends on the area, the speed, and the angle of attack, and there will be some combination best for each set of conditions. To meet these conditions, varying from time to time throughout the course of a flight, a correlative variation in wing area is needed.

To some extent the same ends may be met by changing the camber or curvature and form of the fore and aft section of the wing.

Thus, when the camber or fore and aft curvature is increased, the form will be more suitable for landing at a reduced speed, while the curve flattened and camber reduced the form will more readily favor the attainment of relatively high speed.

The problem of an adjustable wing, either as to extent of area or camber or both, is a favorite one with students of aeronautics, and we may hope for some measure of useful and practical solution. Thus far, of the many devices, and forms proposed, none has so far fully justified itself as an altogether satisfactory and practical solution of the problem.

MOTIVE POWER.

Passing now to the motive power and its application to the propulsion of the airplane, a most interesting and important series of problems challenges our attention. Only the more important can be noted here.

Fuel.—One of the most important of these is that of fuel. What is to be the future fuel for the airplane or for aerial navigation in its wider aspects? How long will our stores of crude petroleum oil from which we now obtain our petrol or essence of petrol, as it is variously termed, continue to furnish this all-important element in the present program of power development? Doubtless there are large stores of petroleum oils yet undiscovered, but we may safely assume that we are using up a supply in the nature of a bank deposit. We are using our principal and not living on the interest. So far as we know, nature is not now engaged in making for us petroleum oils, certainly not in any proportion to our rate of expenditure. To such a general program of consumption there is, of course, but one end—ultimate exhaustion. This is, of course, only one phase of the overshadowing menace which the modern social and industrial world must face some time when our present supply of carbon and hydrocarbon fuels begins to become exhausted, unless, indeed, we develop or discover in the meantime some other source of energy which will adequately take their place. This is perhaps a question which need not seriously concern the present generation, but when we take a long look ahead—a look, for example, as that covered by the development of Europe from the days of the Cæsars or even from the time of, say, Galileo—we may realize with startling emphasis the need of foresight with regard to a source of energy adequate to the world's demands. Various ages have been designated as of stone, bronze, etc. The present might well be designated as that of natural energy. Our entire civilization, in a material sense, rests upon the utilization of sources of natural energy which are not inexhaustible and which are, in fact, becoming exhausted, in some cases, with menacing rapidity. In the meantime we must, and presumably we shall, make some shift to tap efficiently other sources now known, or we may haply discover sources which to-day lie beyond our present vision.

A long look ahead for aerial navigation therefore shows that if the present line of development is to continue there will be a serious problem to be met sometime, and that perhaps before many decades—the problem of a fuel suited to the needs of aeronautical prime movers, at a time when present petroleum sources will no longer yield the supply which we now accept and use with so little thought for the morrow.

But with regard to the question of fuels we need not go so far afield as to look into the coming decades for interesting and important problems. Perhaps the one most pressing for present solution is the question of what is the best fuel for the modern aviation engine, having in view the three requirements—power, economy, with reliability and durability. Out of the exigencies of the present war have come many serious and extended researches relating to the problems of military aviation, and of these none is perhaps of greater significance regarding the future of commercial aviation than the studies which have been made regarding aviation fuels. While matters relating to the problems of military aeronautics must be spoken of with much reserve, it will perhaps be permissible to say before this audience that from these studies three principal results seem to have been rather definitely established. These are—

(*a*) As between the various grades of aviation motor fuels which have been used during recent years, and comprising a rather wide range of composition and of physical and technical characteristics, there is but little to choose from the standpoint of power or economy alone. This assumes, of course, that the fuel is a genuine motor fuel and the results regarding power or economy relate to an assumed period of effective operation under such fuel. It must not, however, be assumed that there are no differences in power or economy traceable to the fuel employed, for such is far from being the case. It is, however, within the limits of reasonable statement to say that such differences are relatively small and in most circumstances would not of themselves constitute a determining or controlling factor.

(*b*) As between such motor fuels marked differences do seem to be indicated as regards their influence on the life and reliability of the motor, especially their influence on long-time tests or in actual service on long-time flights.

(*c*) For the various fuels, in order to realize the best results either as regards power, economy, or life and reliability, special and individual carburetor adjustments are necessary and such as can only be determined by trial under actual working conditions.

It may perhaps be further said that the problem of an excellent and reliable motor fuel for aviation purposes seems to have been satisfactorily solved. Its specifications and range of characteristics, physical and chemical, are pretty well established, and so long as our source of motor fuel supply is to be found in petroleum derivatives, we seem to have reached a reasonably satisfactory determination of the best combination of such derivatives for the various requirements of aviation service. These characteristics, which must be considered as a part of the great body of military information, and which can not for the moment be put down in plain print, we may hope will in due time become available in the arts of peace and for the development of commercial aviation in its various fields of promise.

With the problem of fuel that of the prime mover or engine is closely related. Is the present type of engine to acontinue or is it only a passing stage to some more perfect form? This is a question, interesting, indeed, for speculation but hardly to be considered in comparison with actual present-moment problems. The present engine and its application to the propulsion of the airplane does, furthermore, present no lack of interesting and important problems, and among these a few of the more pressing may here be noted.

First, the problem of gross power. How much power can we put in an airplane or airship of no matter what type or form? This divides immediately into three subsidiary problems, as follows:

(1) How much power from a single cylinder?

(2) How many cylinders for a single engine?

(3) How many engines for a single airship?

In the way of power per cylinder we are now reaching close about 40 horsepower as a maximum.

In the way of cylinders per engine we have reached a stage of development where the 12-cylinder engine is quite a standard type, and higher numbers such as 16 and 18 represent only questions of detail. It is not too much to say that the 600-horsepower engine is quite within the reach of present practice and may be realized as called for. We have long since become accustomed to two and three engines on a single plane and are now seeing four engines in various recent designs. It is therefore clear that if a power plant of 2,500 horsepower on a single structure is wanted, it is quite within the scope of present practice to realize and provide such a plant.

And if four engines of 500 or 600 horsepower each, there is no reason why the number may not be increased, at least to a point beyond the present apparent need for power on a single structure.

On the other hand, it must be admitted that, having in view the limitations of present practice, the most simple and in fact the only reliable way of extending power is by a multiplication of the number of cylinders rather than by an increase in the size of the latter. The fact that a 2,000-horsepower equipment would presumably require from 40 to 60 cylinders shows the formidable degree of multiplication of small elements required to realize such a result. The real problem of size or capacity of engine is therefore one of power in a single cylinder. What can be expected in this direction, and in what way shall search be directed?

The present limitation arises largely as a matter of cooling, and it is in this direction that search may well be made for ways and means of effectively increasing the power capacity of a single cylinder in an engine of the aviation type. This is a problem which is distinctly outstanding and well worth our serious attention and study.

The carburetor.—Another problem connected with the engine is that of the carburetor. At the start of aeronautic engineering the carburetor naturally took its initial form and arrangement from the already fairly well developed automobile engine carburetor. This was but natural since both engines are of the same type and both use the same general form of fuel. In respect of the conditions of operation, however, there is a marked and important difference. The automobile operates at or near a fixed level and hence in an atmospheric medium of sensibly fixed pressure and density. With the airplane the case is very different. The latter may change its level by thousands of feet in a few minutes or even seconds, as in vertical or nearly vertical dives, rapid spirals, etc. This difference in the conditions or operation introduces a factor of distinct significance and of great importance in the design and disposition of the carburetor. Experience in the air has clearly shown the importance of this new factor, and it is not too much to say that the problem of the entirely satisfactory carburetor, capable of automatically answering to the various atmospheric conditions under which it must work, is distinctly an outstanding problem. It is true that much progress has been made, and as the result of laboratory research, checked by actual experience in the air, we now know much better than, say, two years ago, the fundamental conditions which must be met by the carburetor for the aeronautical engine. The present solution can hardly be considered as final, however, and we may fairly admit that the whole problem of carburetion, including the manifold supply of the carbureted mixture to a multi-cylinder engine, should, as soon as may be, receive a thorough and fundamental restudy in the light of the information to be drawn from the experience of the past three or four years.

Ignition.—Another problem which we should view as outstanding is that of ignition. It is true that ignition, as now realized with the best equipment, seems to be fairly reliable and effective. But the whole programme is open to the objection of requiring an entire electric power plant of a highly specified type, together with electric conductors and the spark plug for producing the spark between the discharge points within the cylinder, represents a very complicated and highly specialized device for producing the initial ignition within the body of compressed fuel mixture. In its present state it is a marvel of scientific and technical development, and it does its work; but it is complicated and subject to many possible modes of derangement, and, as we all know, has been and is still the seat of some of the most serious of the engine difficulties to which the power plant as a whole is subject.

I have never been able to persuade myself that this exceedingly complicated and specialized auxiliary equipment was to be the final solution of the problem of producing ignition in an internal combustion engine. If we can anticipate the explosion engine of the year 1968, assuming that our grandchildren are still dependent on hydrocarbure fuels at that date (and, furthermore, that they are still available), it would seem as though some more direct and simple mode of initiating the combustion in the cylinders would have been found. Still, otherwise, we may say that on the law of probability the chances are overwhelmingly against our having at the present moment developed the very best method of ignition. The laws of physics and chemistry, by a probability which almost reaches certainty, contain some potential combination of factors which will permit of eliminating much of the complexity and delicacy of adjustment which is so characteristic a feature of the present mode.

It is perhaps proper to add here that studies in this direction have already been made, and with results which offer promise of interesting developments in the future. The path of perfection is likely to be not a short one, however, and we can see no prospect of any development in the to-morrow of progress likely to displace electric ignition. There must, however, be some better way, and if not to-morrow, then some other morrow should see it made available for use.

The problem of ignition is, then, one which is distinctly outstanding, one which by its importance merits the most careful study, and one which at least offers reasonable ground for hope of a successful and relatively simple substitute for the present mode.

MAINTENANCE OF POWER AT ALTITUDE.

We come now to a problem of the very highest present and future importance, that of maintaining the power of the engine at high altitude.

The situation as it develops in the case of an airplane mounting to higher and higher levels in the atmosphere is readily appreciated with a moment's thought.

The power of the engine arises from the combustion of vaporized hydrocarbon fuel. The power per cycle for a given cylinder will, therefore, to a first approximation, and assuming a sensibly constant efficiency of thermodynamic transformation, vary directly with the weight of the fuel which can be burned per cycle. But this in turn depends upon, and is conditioned by, the amount of oxygen which can be drawn into the cylinder per intake stroke of the cycle. But the oxygen is brought in as one of the constituents of the atmosphere, and hence the amount of oxygen available per intake stroke will depend upon, and be directly proportioned to, the amount of air which can be drawn in. But in terms of volume, just a cylinder full or more exactly, just the volume represented by the piston displacement in moving from one end of the stroke to the other, can be brought in. Hence we may at least depend on what we may term a cylinder volume of air, no matter where we are. But just here arises the trouble. The actual weight of air depends conjointly on the volume and on the density, and, unfortunately for the aeronautical engine at least, the density of the atmosphere decreases steadily with altitude, so that at 15,000 feet, for example, the density is only about 60 per cent of the normal density at the earth's surface. It is clear, then, that an aeronautical engine, other things equal, will draw in per intake stroke only about 60 per cent of the weight of air at this altitude as compared with the indraft at the earth's surface. Hence it will be able to burn only 60 per cent of the fuel and with equal efficiency will develop only 60 per cent of the power.

But here we must stop for a moment and inquire as to the effect of such reduction of power on the speed of the airplane. We know that, other things equal, the resistance of an airplane to propulsion through the air at uniform speed varies directly with the density of the medium. Hence with the same speed as when near the surface of the earth, and at the same altitude and angle of attack, the airplane at 15,000 feet elevation would experience only 60 per cent of the resistance, require 60 per cent of the thrust, and, at constant revolutions of the propeller, 60 per cent of the power from the engine. It appears, therefore, at first sight as though we had lost nothing in speed by the reduction of the power of the engine. If the latter has been reduced to 60 per cent of its amount at low levels, so has the resistance and power required, so that the speed realized should remain the same.

Such would, indeed, be the case if this were all, but unfortunately other considerations enter, and the simple relation of uniform speed at varying altitudes can not be realized without compensating features.

Thus, if at a constant speed and constant angle of attack for the wings the resistance to propulsion is only 60 per cent as great at the altitude of 15,000 feet as on the ground, it is unfortunately the same for the lifting force developed by the wings. This also is only 60 per cent as great, while the weight of the machine remains sensibly constant at all altitudes. Let us grasp this fact clearly that while, at constant speed and attitude of flight, the resistance, the lift, and all other aerodynamic forces involved vary directly with the density of the air and decrease with the altitude, the weight of the machine and the lift necessary for support remain sensibly unchanged. Hence at the same attitude of flight the lifting force at a higher altitude and under the same speed will no longer support the plane, and unless something is done it would be unable to maintain horizontal flight at such altitude.

Two courses are, then, open for consideration, as follows:

(1) We may seek to increase the speed until at such increased value the lift will equal the weight of the plane. Under the conditions assumed this would involve an increase of speed of about 30 per cent, thus increasing the resistance to propulsion by nearly 70 per cent, or bringing it back to its value at low altitude. But this resistance overcome at the increased speed would mean an increase in the required horsepower of 30 per cent as compared with that normally developed at low level, while with the actual indraft of air, and, even allowing for the increased speed, only some 78 per cent of this, or 60 per cent of the needful amount, would be developed. Hence no such speed could be realized, and the support of the unvarying weight in the rarefied air can not be realized in this manner, and must be sought otherwise.

(2) Instead of seeking for the necessary lift by increased speed, we may seek it by changing the angle of attack—by changing the flying attitude of the plane so that at the same speed, for example, the lifting force will be greatly increased. In this manner the needful lifting force may indeed be realized. But, unfortunately, with the increase in lifting force will come also an increase in head resistance, not proportionally, but still a definite increase. This will mean that the actual resistance at, say, 15,000 feet elevation will be greater than 60 per cent of that at low elevation, and with 60 per cent of the power available per cycle the original number of revolutions can not be maintained and a reduction in speed will result. With this reduction in speed will come a further loss in lifting effect and need for a further change in the angle of attack with increased head resistance; until finally, at some reduced speed, a condition will be found where the needful support for the weight of plane may be realized and the resistance to propulsion can be met by the thrust or pull developed at the propeller. In these conditions horizontal flight again becomes possible, but at a speed somewhat below that corresponding to low-altitude conditions.

In addition we must reckon on a diminished efficiency of the engine with decreased power, and with the probability of a loss in propeller efficiency with the resultant change in speed. Thus, if an engine is primarily designed to work at its best efficiency and under its best conditions at or near full atmospheric pressure and density, it will not work with equally good efficiency at high altitudes in rarefied air and when developing only about oue-half the power for which it is primarily designed.

In brief, at an altitude of, say, 15,000 feet the plane must fly at a less advantageous angle of attack but with more resistance, and that the engine will be able to burn only about 60 per cent as much fuel and will transform the resulting heat less effectively, than when at low altitudes. Therefore, the power developed will be less than 60 per cent and insufficient to maintain the same speed; and with diminishing speed there may be further loss of efficiency in the propeller and a further loss of speed, until finally matters become adjusted at some value usually definitely and sometimes considerably less than that corresponding to low-level conditions.

As an over-all practical result an airplane normally loses horizontal speed as it ascends to higher altitudes.

Confronted with this fundamental fact, what is to be done? Such loss of speed, especially in a military sense, is or may become very serious, and one of the large and definitely outstanding problems in aeronautical engineering at the present time centers about the possible ways and means of meeting this condition.

The obvious proximate solution is to avoid, so far as may be, the decrease in the amount of air handled per intake stroke of the piston as the plane ascends to higher and higher altitudes.

Broadly, two courses are open. First, we may definitely and frankly design the plane and engine for a certain desired performance at a given altitude, say 15,000 or 20,000 feet. This is a straightforward problem in aeronautical engineering. Given the desired schedule of operation and the altitude, we can determine the resistance to be overcome and the horsepower required, and can design the engine accordingly. In such case the volume of the cylinders will be suited to the rarefied air in which the engine is to work, and all proportions and details will be worked out on this basis.

It will be obvious that such an engine will have much too large a piston displacement volume when at low altitude—that is, it will be oversize and overpowered relative to the plane. In fact, operation near or on the ground under the same adjustments as at altitude would be quite out of the question. Means must therefore be provided for reproducing, when on the ground or at low altitudes, substantially the operating conditions at high altitudes and low air density—that is, the conditions for which the engine was designed. This may be most conveniently done by throttling down the air intake so that while air at or near full sea level density may surround the engine, it will be reduced in pressure at the intake throttle to such a degree that the amount actually taken into the cylinder will only equal that which would normally enter, without throttling, at high altitude.

On the other hand, we may definitely design the engine for operation at or near sea level and with size of cylinders and all proportions and adjustments worked out accordingly, and then by a supplementary device endeavor to maintain, or to nearly maintain, such conditions within the engine itself even if it is at high altitude and surrounded by air of a lower density.

This solution calls for some supplementary form of compressor or equivalent device which shall operate on the rarefied air as a first stage and raise it from the low pressure characteristic of the altitude up to or nearly to normal low-altitude pressure and density.

Each of these alternatives represents a perfectly possible solution. Each has its special advantages and disadvantages. Each has its advocates as a solution of this important problem.

The first solution is the simpler of the two, since it involves no special or additional device for compressing the air. It does, however, mean extra weight in the engine which is always there and which will reduce correspondingly the net carrying capacity of the plane.

On the other hand, the compressing device of the second solution is not easy to realize satisfactorily and it also involves extra weight, though presumably less than in the case of the first solution. Again, its operation as a separate or independent unit for realizing a preliminary compression of the air is less efficient than to do the whole compression in the engine itself and by the engine piston, as in the first solution. Only extended and careful trial will presumably be able finally to decide which is on the whole the better solution of the two.

The reserve necessary with regard to military matters makes it unwise to attempt to give any account on this occasion of just where the matter stands with regard to this problem, but it will at least be safe to note that it is a problem which is attracting much attention and study on the part of the various allied Governments, and that much valuable information is being developed, and on which we may hope that some satisfactory solution may be based.

THE AIR SCREW.

We now turn our attention for a few moments to one of the most intricate and interesting of the many problems presented to us, that of the air screw or propeller.

The function of the air screw is, of course, to take the torque of the engine and to transform it into a propulsive thrust; or otherwise to take the power given by the engine to the crank shaft and transform it into driving or propulsive power for the air plane. The problem is further complicated by the fact that, expressed in terms of a power relation, it is not simply the question of an engine handing so much power over to the air screw for the latter to transform into propulsive power. Instead, the power which the engine itself can develop is dependent on the propeller and likewise on the airplane to which they are both attached. We have here, in consequence, a series of complicated implicit relations, and from which the propulsive characteristics of the plane-propeller-engine combination take their origin. In fact, it must never for a moment be forgotten that the moving airplane is in effect an airplane-motor-propeller combination and that no one of the three can be determined independent of the other two.

Without entering into any detailed discussion of this problem, it will be clear that the air screw will exercise a controlling influence on the power which the engine can develop. Thus, it is evident that an aeronautical engine, in order to develop power, must be permitted to move its pistons, to revolve its crank shaft, in other words, to make revolutions; and, other things equal, the power developed will vary directly with the revolutions which can be realized. Again, it is easy to see that the size and amount of surface of the air screw blades will present a controlling feature regarding the revolutions which can be realized. Thus, the air screw may be enormously oversize, too large in diameter, and presenting a large and unwieldy surface to the air. Suppose this to be the case with a plane of size suited to the air screw but not to the engine—that is, the engine is far too small for either air screw or plane. In such case the engine simply will not be able to make its normal number of revolutions. It will be held down by the excessive resistance to rotation presented under such circumstances, and may thus develop far less than the normal power which it is capable of under proper conditions. Many other combinations may occur which we can not stop to discuss or even to mention. Broadly speaking, the plane, the engine, and the air screw as the propelling agent form a most closely knit combination, and each interacts in a more or less controlling manner on the operation of the other two.

In order even to make a start with the problem of the air screw, it is therefore necessary to assume conditions regarding both the plane and the engine. If these conditions as assumed are then realized in practice, and if the design has been well carried out, the anticipated results may be reached. If, on the other hand, the assumed conditions are not realized as regards the plane and the engine, then no matter how well the design of the air screw may have been carried out, the anticipated results will not be realized. No matter how good the air screw may be by itself, no matter how carefully designed and constructed, no matter how faithfully, it may be able to realize the conditions for which it is designed, if there are not the conditions under which it is actually placed for service, the results, economic and otherwise, will be unsatisfactory; not necessarily by reason of any fault in the air screw as such, but due simply to its lack of adaptation to the conditions of operation. An effective air screw is therefore not only one which is properly designed and constructed in itself, but also one which is permitted to operate under the conditions intended and contemplated in the design.

The general problem of the air screw is by no means, however, to be classed distinctively as outstanding. Instead an enormous amount of work has been done on it, both theoretically and experimentally, and in its main features it has been brought fairly within the limits of a solved problem. There have been three modes of approach, briefly as follows:

(1) The analysis, geometrically, of the blade of an air screw into a series of elements occupying each a narrow strip running across the blade from leading to following edge and making up, by their summation, the blade, as a whole. Each of these elements or strips is then considered as, in effect, a little elementary areofoil and for which the usual aerodynamic characteristics are readily determined, either by direct experiment on a model or by selection or interpolation from and among the large amount of available data regarding such areofoils which have already been submitted to experimental investigation. With such data in hand relating to the series of elements going to make up the blade, it is a matter of simple computation to combine them in such manner as to represent the action of the blade as a whole, under the conditions assumed, and thus, in general terms, the problem is solved.

(2) A law of similitude is assumed and a small model propeller is tested out experimentally and under conditions which permit, under the law of similitude assumed, the translation of the observed results for the model into the probable results for the full-sized air screw.

(3) Full-sized air screws are tested out as nearly as may be under flying conditions and are made the ultimate basis of design.

The limitations of method No. 1 arise from the following:

(*a*) The coefficients derived for areofoils correspond to straight line motion between the air and the foil, whereas in the air screw the relative motion is in a helical or spiral path.

(*b*) The actual velocities for which such coefficients are derived are usually for speeds not exceeding 60 or 70 miles per hour, whereas the actual speeds of the tip elements of air-screw blades may move at speeds of 500 m. h. and upward. The extent to which the usual square of the speed law may be extended to such values is not as yet fully known.

(*c*) The coefficients used are derived for the various areofoil sections or elements individually, whereas in the actual air screw they all act conjointly or collectively in making up the air-screw blade.

Application of method No. 1 can not therefore be made except in so far as it is justified by actual and final experience on full-sized forms under flying conditions.

Method No. 2 (that with reduced-size models) has the limitation that the law of similitude employed is of necessity not exact but approximate, and the degree of reliance which can be placed on results thus found can again only be determined by ultimate reference to full-sized forms under flying conditions.

Method No. 3 (that with full-sized forms under actual flying conditions) has the limitation of very high cost, both in equipment and time, and as a result of which only a relatively small number of forms can actually be subjected to adequate test in this manner.

Again, method No. 1 (that of computation based on coefficients determined by laboratory experiment) has the advantage of requiring only a pencil and pad of paper with a table of predetermined coefficients. No. 2 (that with the small models) has the advantage over No. 3 of relatively small cost, of permitting the tests to be carried out in a wind tunnel with all conditions under control, and finally to permit of carrying quickly through the test program a very large number of types and forms. It should, perhaps, be stated here that as between methods No. 1 and No. 2, the latter is accepted as much the more reliable of the two. In fact, it is not too much to say that when used with judgment, it furnishes a very satisfactory and well-nigh universally accepted method for dealing in a laboratory way with most problems of air-screw design and operation.

These phases which thus stand out represent in effect the lack of an adequate correlation between the three methods of approach as above described.

It is obvious that if we could develop an adequate and reliable correlation between the results of the computation according to method No. 1, and the final test under flying conditions according to method No. 3—if, in other words, we could adequately determine the error of No. 1, and hence the correction to be applied in any given case. then a pencil and pad of paper would go a long way toward furnishing the material for the solution of the problem of air-screw design, once that we are permitted, of course, to assume a definite set of operative conditions.

Or, again, if we could know more accurately and more widely the character and amount of error to be anticipated in the use of the small models according to method 2, we should be in a position to use the experimental model method with better assurance of definite and reliable results for the full-sized screw later to be constructed.

It seems likely that this final correlation of computation with ultimate result may best be made in two stages. The first should comprise a careful study of the relation between the results derived by the computations of method 1 and the model tests of method 2. Such a correlation would then permit us to pass readily from the results by computation to the probable results by model.

The second correlation should then comprise a series of comparative tests to determine with sufficient generality of application the character and amount of correction to be applied to the results of model test in order to satisfactorily reproduce the results to be expected from full-sized forms.

This would by no means require the testing of a full-sized form corresponding to each model. If so there would, of course, be no use in making model tests. The whole program might as well be carried out directly by tests on full-sized forms. It appears reasonable to expect, however, that a well-selected and not too numerous series of tests, properly distributed among the various characteristics of form and of operation, would serve adequately to give the correlation desired.

With such correlations established we should then have two methods—Nos. 1 and 2—available for the design of air screws. No. 1 available with no more than a pencil and pad of paper (once the standard section coefficients determined) and No. 2, by model, ready to supply a vast amount of detailed information regarding operation under varying conditions, and which may be realised rapidly and effectively once the model is made.

If we have spent so much time over these matters relating to the air screw, it is because of its importance as an element in aerial navigation, and in order that we may the better note just what part of the general problem is still outstanding.

This, as we have seen, lies primarily in the matter of the correlation between the three methods outlined. There is, indeed, need for continuing experimental research, especially on systematically selected forms. both model and full size; and such continuing experimental work combined with carefully directed studies of correlation will go far toward giving us an assured and adequate basis for the practical solution of the air-screw problem as applied to aerial navigation.

Reaction between air screw and plane.—Perhaps the widest and most important outstanding problem in connection with airplane propulsion has relation to the reaction between the plane and the propeller—the influence of the structures adjacent to the propeller on its performance, economic and otherwise, and the influence of the propeller on the plane, both as regards its lift and its net resistance to propulsion. This is a field which is largely outstanding. It must be attacked chiefly by the experimental method—by model with results checked up by comparison with full scale trials so far as practical.

Multiple air screws on one shaft.—Of a closely related nature is the problem of the interaction of two or more air screws on one shaft. This is a problem which is becoming of importance in connection with the increase in power of airplane power plants and with the fitting of more than one air screw on the same shaft.

This likewise is a problem which must be approached experimentally—again through model research checked up by comparison with full scale tests. A beginning has been made on this most important and interesting problem, and we may expect in a not distant future to find it brought within limits of control similar to those surrounding the problem of the individual air screw.

Air screw with adjustable pitch.—In addition to these problems which relate to airplane propulsion in its general aspect, and more especially when for the sake of simplicity we assume that the airplane remains under a uniform regimen as regards external conditions, there arises a problem of very great present importance, that of some form of adjustment in the technical characteristics of the plane as a whole permitting it to be made responsive to variations in the regimen of operation, as, for example, change in the density of the air due to change in altitude, or change of regimen required for climbing flight as compared with horizontal flight.

In connection with the prime mover, mention was made of the very important problem of maintaining power at altitude in spite of the decrease in the density of the air. In reality this problem is very intimately bound up with another of scarcely less importance, that of devising means for effectively using such power for propulsive purposes. Without attempting any technical discussion of the question it will be apparent that the whole problem of the operation of the air screw as a means for absorbing the power of the prime mover and converting it into the propulsion of the plane will depend on the density of the medium in which and on which it operates. Again, in climbing flight a part of the weight of the airplane is carried by the pull or thrust of the air screw. In horizontal flight it is all borne by the planes (assuming the air-screw shaft then horizontal). Hence the pull or thrust of an air screw, and, indeed, its whole regimen of operation, may vary widely according as the plane is climbing or flying horizontally. It thus seems reasonable to conclude that for the best results there should be provided some mode of adjustment or compensation so that the air screw, as it finds itself operating in a medium of continuously decreasing density, or as it finds itself called upon for varying amounts of thrust or pull with varying angles of climbing flight, may be correspondingly adjusted in order to give continuously the best results.

The problem is further complicated by the fact that the airplane itself needs a correlative adjustment. As we have already seen, the one factor in aerial flight which remains sensibly constant under all conditions and at all altitudes of flight is the weight of the plane and its equipment. The vertical supporting force gained from the reaction of the air must, therefore, be maintained constantly equal to this weight at least for the conditions of horizontal flight, while for climbing flight the weight will be divided and borne partly by the supporting planes and partly by the air screw. The problem of the economic use of power at varying altitudes and under varying angles of climbing flight involves, therefore, the following chief elements:

The weight of the plane.
The surface of the wings and their aerodynamic characteristics.
The angle of attack of the wings.
The speed.
The power developed by the engine.
The revolutions of the air screw.
The area and form of the blades of the air screw.
The pitch of the air screw.

These various factors react and interact in a most complex manner, and any attempt to discuss the problem in detail would carry us too far afield on the present occasion. We may note, however, that the angle of attack is the one feature about the plane which may readily be varied, while there is no feature of the propulsive agent, the ordinary air screw, which admits of equally simple correlative variation. What is needed with regard to the air screw is, indeed, some means of realizing an adjustment correlative to the change in the angle of attack for the plane. To this end a change of pitch is most suitable, some means of varying, at the will of the pilot, the pitch of the screw in order that, with the fixed diameter and area of surface, and with the work available per revolution of the engine as affected by the density of the air, the pitch may be so adjusted as to secure the number of revolutions best adapted to the economic use of the power given out by the prime mover. This will then insure the thrust needed to overcome the resistance of the plane at the angle of attack and speed which taken conjointly will give the lifting force needed to support the weight of the plane, either in whole or in part, according as the plane is flying horizontally or climbing.

All of this somewhat complicated statement means simply that what is wanted is an air screw with blades adjustable for pitch. Such an air screw may be realized by so pivoting the blades that they may be turned about a radial axis, thus changing their angle relative to the axis of the screw itself. Extreme changes of such a character result in a very wide variation of pitch from root to tip, and in the end will result in a serious loss of efficiency. There are, therefore, two problems involved:

(1) The aerodynamic problem of determining the best form and proportions of an air screw, the blades of which are intended to be pivotable in this manner, so that under the widely changing conditions of flight which may be met with, there may be effective operation and a well-sustained efficiency.

(2) The mechanical problem of so designing and building an air screw with adjustable blades that it will meet the rigorous requirements imposed upon it by the exacting conditions of airplane navigation.

It is perhaps not too much to say that the first problem is already well in hand. We know reasonably well what forms and proportions to give to such an air screw, and if it was only a matter of design or of the determination of form and proportion the problem could hardly be called outstanding.

As much can not be said regarding the second problem. The practical construction of an air screw with adjustable blades is not an easy matter. Several modes of construction have been attempted but with only moderate success. The problem is clearly defined, of the highest order of importance, and is outstanding as one of the appliances for which the art of aerial navigation is definitely in waiting.

STABILITY AND CONTROL.

The three fundamental requisites of an airplane are strength, movement, and stability with control. We have noted some of the problems arising under the requirements of strength and movement or propulsion. We may now turn very briefly to a glance at the situation regarding stability and control. Any detailed discussion of these problems would be quite out of the question on the present occasion, and time in any event will only allow us a brief glance at the general situation.

Regarding stability and control it is not too much to say that the general principles underlying these characteristics of an airplane are now reasonably well understood, due largely to the splendid theoretical and experimental investigations initiated by British scientists, and to which certain workers in the same field in the United States may have contributed something, and by no means overlooking certain important contributions by French and Italian investigators. These investigations, both analytical and experimental, have placed the study of these subjects on a reasonably sure foundation, and have served to mark out the way to secure any desired degree of stability which may be desired or which may be consistent with other valuable qualities. We are here confronted with one of those situations so frequently encountered in scientific and technical work, where a choice must be accepted on some middle ground between wide extremes, and where the attempt to secure some desirable quality in high degree may lead to a limitation of desirable qualities in other directions.

So it is with stability and control. If stability is carried to an extreme, then mobility and quickness of maneuvering are reduced and control in the sense of ready response is lacking. For military purposes, especially for machines of the fighting type, where mobility is of the highest importance, this would be a serious shortcoming, and hence such machines can not be given too much stability in the ordinary sense of the term. On the other hand, for heavy machines of the bombing type, where mobility of evolution is not so vitally important, the margin of stability may be greater. Going to a still further extreme, it is perfectly easy to build a safe, moderate speed family carriage sort of machine, which will be stable and secure under almost any conditions likely to develop. Such machines would be scorned by fighting pilots, but when civil aeronautics begins to come into its own after the war and under peace conditions, and there comes a demand for safe machines for civil purposes, including family outings for the week end from the city to the country or to the seacoast, then we may anticipate a larger recognition of the qualities making for safety and stability, and we shall find machines provided having such characteristics and in practically any desired degree. Here again, however, there will be degrees of choice, because it will be found that with too high a degree of stability what may be termed the riding qualities of the plane will be poor, while with low stability the riding qualities may be much smoother.

The general problem is, therefore, pretty well solved, so far as the groundwork is concerned. This does not mean, however, that there is nothing further for us to learn in this connection. There are many problems of a detailed nature inviting the student of this fascinating field of study, and the solution of which will serve to round out and broaden our general grasp of the problem. In particular, we need further study on the interaction between elements which insure stability and those which permit mobility and readiness of response to control agencies, to the end that we may control more effectively the combinations which may be desired regarding stability and mobility of evolution.

Again, while the elements of control are well understood, there is room for further study as to the best means of actually developing the control forces required and of applying them to the plane itself. These are partly aerodynamic and partly structural problems, each phase reacting more or less on the other.

One instance of problems of this character will serve to illustrate the type.

We know that an airplane is provided with rudder surfaces of two kinds, one to determine movement in a vertical motion, up or down, and the other to determine horizontal motion, right or left. But these motions, vertical and horizontal, assume that the plane itself is horizontal or sensibly so. However, when a plane is circling on a steep spiral or making a quick turn, it is inclined or "banked" in order to avoid side slipping, until, in extreme cases, the wings are nearly vertical, and frequently much more nearly vertical than horizontal. In such cases the functions of these control services are reversed. Those which, with normal aspects, serve to produce movement right and left will now serve to determine motion rather in a vertical direction, and those which formerly served for movement up and down will now serve to determine motion to the right or left. For intermediate angles of bank each set of control surfaces will give control forces in both directions, up or down and right or left.

Now, it is by no means sure, having in view this double and interchanging function between these two sets of surfaces, whether we have as yet realized the ultimate and best arrangement either as regards the surfaces themselves or their control by the pilot.

It seems decidedly probable that we have not and that some arrangement yet remains to be devised which will be more effective in the matter of this double and interchanging function of control and simpler in its relation to the pilot.

ARMAMENT AND INSTRUMENTS.

There still remain two large and important fields, rich in aeronautic problems. These are armament and instruments. I shall attempt no more than the briefest general reference to these two classes of problems.

Those arising under the head of armament are, of course, strictly military in character and but little of interest could, in any event, be said in a public address. Such problems relate naturally to the number, type, and size of guns to be carried, their mounting and special sights; bombs and devices for carrying, aiming, dropping, etc.; questions of armor and protection of vital parts against gunfire or shrapnel bursts, etc.

Expressed in their most general terms these problems resolve themselves into an attempt all along the line to meet the requirements imposed by the desired military uses of the plane and to anticipate or improve upon the devices and designs of the enemy in the same fields.

Regarding instruments, little more specific can be said. This field does, however, bristle with problems of the highest interest to the scientist, and may well challenge his best efforts. It is interesting to note the extent to which the modern airplane has become a flying meteorological and physical laboratory. Thus, a recent list of airplane instruments shows some 25 or 30 different instruments and devices, not indeed all to be carried on one plane, but all included in the general aeronautic military program and each serving some specific and important purpose.

With these instruments, as with armament, the problems reduce themselves to an effort to meet the military or the navigational and operative requirements of the situation, and in these days of war in particular, to anticipate or improve upon the similar devices and designs of the enemy.

Much of the work relating to these problems under armament and instruments is already done and well done. There do remain, however, many problems, especially of detail or of improvement, and which must be considered as outstanding; but of these I shall attempt no mention or discussion.

By way of conclusion, reference may, for a moment, be made to a problem of the most vital and far-reaching economic importance, and which will be upon us with the arrival of peace conditions. This is the problem of the best economic utilization of the enormous investment which has been made in aeronautical production, expressed in terms of money and human time and energy, and now represented by factories, machinery and equipment, finished product, trained industrial organizations, human skill, and productive capacity.

The discussion of such a problem might well occupy our careful attention for the entire hour, but I can no more than mention it here by name. We can, however, scarcely overexaggerate its importance, and the appointment of importance commissions in England and in the United States for the study of the problems arising under this general head is an evidence that their serious import is appreciated, and we may hopefully await suitable measures of adjustment against the day when we may again turn our thoughts to the occupations of peace.

And so with all our problems—we can only look hopefully forward for the future to give to us such measures of answer as our patience and study may merit.

The general problems enumerated in the preceding annual reports of the committee have in part constituted the program of work during the past year. Progress has been made in the scientific study and solution of these problems which are considered of immediate importance, and they will be attacked on a larger scale by the committee with the increased facilities and talent which will be available at the committee's research laboratory at Langley Field after the war.

A. *Stability as determined by mathematical investigation.*—A number of isolated experiments have been made upon the stability of airplanes, and the investigation of the behavior of airplanes in gusts has been continued, Part III appearing in this volume as Technical Report No. 27.

B. *Airspeed meters and aeronautic instruments.*—The officers in the Air Services of the Army and Navy have to a large degree handled the development of airplane instruments in their own organizations, and it has been necessary only in rare cases to conduct independent investigations looking toward the improvement of existing instruments. For example, the committee investigated, through the subcommittee on navigation of aircraft, aeronautic instruments, and accessories, a centrifugal type of tachometer designed by a Russian engineer and after finding that it possessed certain advantages over existing types, called it to the attention of the officers of the Air Service. Various other interesting instruments have been experimented upon by the committee, among which was a vertical rate of climb indicator sent to this country from Holland at the committee's request. The development of the Zahm Venturi airspeed meter has also been carried on extensively by the Army authorities with a view to reducing the head resistance of the pressure nozzle and its support. The committee has been active in suggesting improvements and in proposing investigations looking to the improvement of these instruments. These investigations have in the main been carried on at the Bureau of Standards.

C. *Wing sections.*—Extensive data exist in relation to the aerodynamic properties of wing sections, but in widely varying forms and in different publications. An effort has been made by the committee to collect all of this data in one compilation, where it is presented in a uniform manner and in such a way as to make it readily available for the purposes of the designing engineer. In addition to data already published, investigations have been conducted under the direction of the committee upon new types of wing sections. Starting with the section called "Durand 13," which was the section at the 13-inch radius of one of the model propellers used by Dr. Durand in obtaining the data given in Technical Report No. 14, of the third annual report, much work has been done at the Massachusetts Institute of Technology under the auspices of the airplane engineering department of the Bureau of Aircraft Production in developing thick wing sections suitable for internally braced machines. Some sections have also been developed with a high-lift coefficient and having comparatively high L/D values at small values of the lift coefficient. The investigation of wing sections is being continued by the committee with a view to searching for forms having specially desired characteristics, as, for example, a minimum shift of the center of pressure with change in the angle of attack. Combinations of supporting surfaces are also being studied with a view to the determination of their mutual reaction and interference. Special attention is being given tandem arrangements.

D. *Engines.*—The most outstanding feature in this field of aeronautic development in this country is the continuous improvement and power increase of the Liberty 12. The first eight months of the year witnessed the power per weight ratio, as expressed in pounds per horsepower output, improved from 2 to 1.85 when the engine was operating on 68° B. standard gasoline at the standard reference speed. At maximum power this is further reduced to 1.70

pounds per horsepower. With special fuel, the figure for standard speed is further improved to 1.75 and for maximum power to 1.65. This is a very creditable accomplishment and indicates that healthy development which can be based only upon a correct engineering foundation. Of interest in this connection is the note on "Evolution of aircraft engines" in another part of this report.

Liberty 12 production during the period from January to November 1, 1918, increased from 1 engine per day to approximately 150 per day. At this rate of progress a daily production of 230 engines would be reached by the first of 1919. This demonstrates conclusively that while the modern high duty aircraft engine necessitates a rather intricate mechanism and calls for the utmost accuracy in many of its parts, it is quite possible to produce it in large quantities with American manufacturing methods. It is, of course, essential that the design should be made in the light of a proper consideration of the limitations and advantages of American manufacturing methods if such production results as have been demonstrated are to be expected.

Although the Liberty 8 was the original form of this development, it had been superseded by the 12-cylinder model, owing to the demand for increased power in two-place combat machines. However, the development of and preparation for production of the 8 was undertaken during the latter half of the year, in order to round out the program for combat machines.

The extensive use of Curtiss OX-5 engines for training was made possible by the satisfactory development and large quantity production of this model. The Hall-Scott A-7a was used in some training planes during the early part of the year.

D-1. The manufacture of engines of foreign design has been materially advanced during the year. The 300-horsepower Hispano-Suiza has been successfully developed and production on it was started. This engine has given some remarkable results in specific power output and thermal efficiency. Like the two Liberty models, it is intended for use largely on combat airplanes.

The Hispano-Suiza 150-horsepower, as well as the Le Rhone 80-horsepower, and the Gnome 100-horsepower revolving engines, were produced in quantity, although the Gnome was used only to a limited extent. All of these engines were used for training purposes.

D-2. The comprehensive radiator research which was begun last year has been completed in some of its phases. It is believed that the results will prove an important aid to the development of rational methods for designing and placing airplane radiators. Some rather revolutionary results have been secured in the effort to reduce the ratio of head resistance to radiation capacity. (See Technical Report No. 43.)

The complete mathematical analysis of the fundamentals of the transfer of heat to a moving air stream is under way, with a view to the establishment of the correct conception of such phenomena. This analysis is being checked continuously against the experimental values obtained.

D-3. The vacuum chamber for testing engines under the conditions existing at high altitudes, which was built at the Bureau of Standards during the past year, has been in continuous use in connection with a comprehensive investigation of the properties of a large number of hydrocarbon fuels. Much work has also been carried out by way of investigating the effect of variations in pressure, temperature, humidity, speed, compression, carburetion, ignition, etc., on the performance of aircraft engines. Most of this work has been done with the Hispano-Suiza 150 horsepower, although the Liberty 12 has also been under test. However, the latter proved rather too large to handle conveniently in the present chamber. (See Technical Reports Nos. 44, 45, 46, 47, and 48.)

The altitude chamber has proved to be a very material aid in the higher development of aircraft engines and fuels. Therefore, two new chambers of larger size are being constructed, together with a new laboratory building to house them. These chambers are so interconnected that the total refrigeration and exhausting capacity will be available for either, and it will be possible to test water-cooled engines as large as 800 horsepower; also air-cooled engines up to about 350 horsepower.

D-4. A somewhat simplified vacuum chamber has been built and used for the study of the functioning of various types of carburetors under varying conditions of pressure, temperature, and throttle opening. Much valuable data has been secured which has thrown light on the problem of compensation for altitude. Two forms of automatic compensation devices have been developed by its aid, which have given remarkable results under test. (See Technical Reports Nos. 48 and 49.)

D-5. The problems of lubrication and lubricants have received much attention and many comparative tests have been run of various oils in aviation engines mounted on a torque stand. A special single cylinder Liberty engine has been fitted with devices for the measurement of temperature and pressure at all of the important bearing surfaces, and this should furnish data of marked value in the study of this problem.

At the same time, a comprehensive research has been conducted in the laboratory, having for its object the determination of more exact conceptions of the relationships existing between the various properties of lubricants. Some interesting results have been secured which tend to show the inadequacy of present specification methods.

D-6. The development of fuels productive of maximum power output, combined with high thermal efficiency, has received attention and much has been learned. The results have served as the foundation for a new series of specifications for the several grades of gasoline best adapted to the requirements of different branches of the air service.

The properties of many mixtures of gasoline, benzol, alcohol, etc., have been investigated, as have those of a number of hydrocarbons which have been chemically modified. Gasoline-benzol mixtures and "hydrogenated" benzol have shown interesting results, by permitting higher compression pressures and temperatures with resultant increase in power output. (See Technical Report No. 47.)

In connection with the fuel research, a comprehensive investigation of the phenomena of flame propagation and combustion has been inaugurated and special apparatus constructed for securing accurate experimental data.

D-7. The work on ignition problems has been largely concentrated on the perfection of the spark plug and the study of the current characteristics of magnetos and battery systems. A new porcelain has been developed by the Bureau of Standards' Ceramics Section, which has greater mechanical, thermal, and electrical strength than any that had previously been produced, either in this country or abroad. This constitutes a marked advance in the art, and the formula of this porcelain has been adopted by a number of manufacturers.

The work on current characteristics of different ignition systems has been of great importance in connection with the effort to determine the exact properties of ignition sparks which insure the most effective ignition with the least energy expenditure. This research is as yet incomplete.

The effect of the auxiliary gap, of differing electrical characteristics, on the restarting of fouled spark plugs is under investigation. Although not yet completed, it has been shown that the correctly designed auxiliary gap is a very valuable aid in overcoming the effects of defective carburetion and cylinder lubrication.

D-8. The problem of supercharging aeronautic engines, in order that the power output shall not fall off with the attenuation of the atmosphere at increased altitudes, has been the subject of much experimental development. The results have been very encouraging, a power output having been obtained at 14,000 feet elevation which was equal to that at sea level. Also, it has been demonstrated that the power output can be increased some 30 per cent at sea-level without serious difficulty.

The solution of this problem will result in the attainment of much greater speeds at high altitudes than those of present airplanes. As most of the long-distance flying will be at high altitude, the importance of this problem is evident. The several interesting types of apparatus are under intensive development.

E. *Propellers.*—The tests of air propellers described in Technical Report No. 14 of the third annual report have been continued during the past year, and the results are given in Technical Report No. 30. In these tests model propellers were selected with a view to broadening the field covered in the previous investigation. A pitch greater than that previously used has been experimented upon, together with varying degrees of blade offset, but with a shape similar to ones previously used. Several propellers of the first series but with less camber have also been tested. In addition to these new models, tests have been made upon the standing thrust and power of all those previously tested as well as the brake effect (negative thrust at low revolutions) of some of these. Some special experiments have also been made, one using two propellers in series revolving in opposite directions; another upon a model constructed in such a manner that the blade angles could be varied throughout a considerable range, thus furnishing some data upon the subject of the variable pitch propeller. Experiments have also been carried out upon model propellers designed and submitted by the Army and also by individual inventors where the design submitted seemed to offer some promise of advancement in the development of air propellers. The committee is extending the investigation of model propellers to include extensive determinations of the mutual reactions or interference upon adjacent structures, such as fuselage or wings.

Apparatus and equipment have been made available which enable free flight determinations to be made upon full-sized airplane propeller performance. It is intended to develop from this work definite relations and coefficients which will enable the designer to make the transition with accuracy from model tests conducted in wind tunnels to actual full-size performance. An analytical investigation of existing experimental results on model propellers is in progress with a view to making available to the designing engineer definite and accurate data upon which to base the calculations of performances of aerial propellers. Theoretical considerations have also been discussed by Dr. de Bothezat, who has developed formulas which add materially to the data already available for this purpose. (See Technical Reports Nos. 29 and 30.)

F. *Form of airplane.*—During the past year there has been no further uniform investigation of this subject. Numerous isolated tests have been made which do not, however, add much to the general knowledge of the subject. Among the large number of inventions examined by the committee during the past year have been many proposals for variation in the form of airplanes, but none has contained points of material value in assisting the development of the science.

G. *Radio communication.*—The problems of intercommunication between airplanes and between airplanes and ground have been developed and have proved of great assistance to the military and naval air forces. Methods of intercommunication, both by telegraph and telephone, have been perfected. Considerable experimentation has been carried on at the Bureau of Standards relative to securing a wind-driven generating unit giving constant power output at all airplane speeds.

H. *Meteorology in relation to aeronautics.*—Considerable work has been done by the subcommittee on the relation of the atmosphere to aeronautics, aided by the staff and facilities of the Weather Bureau, toward making available to pilots and observers information regarding those properties, characteristics, currents, winds, and detailed meteorological conditions of the free air which are of special importance to aeronautics and the safety and economy of aerial navigation.

An effort has also been made to encourage the systematic investigation and observation, by means of kites, pilot balloons, airplanes, etc., of atmospheric phenomena, and, through the agency of the Weather Bureau and otherwise, to provide for the general dissemination of advice based upon observation of atmospheric conditions and to assist in the application of the results of investigations of the problems of aerial navigation.

PHYSICAL PROBLEMS.

Besides the more general problems the following problems of a physical rather than an aeronautical nature are of particular interest, and under same the following progress is noted:

A. *Noncorrosive materials.*—The attempt to prolong the life of iron and steel parts in service by protecting them against corrosion has led to the investigation of many materials and processes for coating. These protective materials fall into three general classes: (1) Metallic coatings; (2) coatings in which the iron to be protected is itself converted at the surface into some inert compound; and (3) organic coatings, such as paints, varnishes, enamels, etc. The organic coatings have received no attention by this committee, but those mentioned in (1) and (2) have been extensively investigated through the subcommittee on noncorrosive materials.

The metallic coatings include all the common metals and alloys which can be applied to steel, namely, zinc and aluminum, which are electropositive to iron, tin, lead, "terne" and other lead alloys, copper, nickel, cobalt brass, bronze, and silver, all of which are electronegative to iron. In the case of the iron compounds the iron at the surface is converted into an oxide or to some other compound, after which it has been found advisable to give the piece an oil finish.

The electrochemical effects, the application of the coatings of the various types, and the resulting microstructure has been closely studied. Methods of preparing the articles for coatings and methods of testing the coatings have also been developed.

B. *Flat and cambered surfaces.*—A number of reports have been obtained relative to tests conducted at the National Physical Laboratory of Great Britain, which contain valuable information on stabilizer, elevator, and rudder fins. The committee has also undertaken a further study of combinations of control surfaces, with a view to the determination of the most effective methods of steering and of control generally.

C. *Terminal connections.*—No comprehensive investigation of this subject has been undertaken, and the isolated experiments made by the industry have not added materially to the knowledge of the problem.

D. *Constructive materials.*—D-1. A continuation of the work done at the Bureau of Standards through the agency of the subcommittee on standardization and investigation of materials for aircraft upon the development of substitutes for linen airplane fabrics has brought onto the market a type of cotton fabric equal in quality, if not superior, to the conventional linen fabrics. (See Report No. 36.) This development work has been carried on in conjunction with the manufacturers, who have materially assisted in the realization of the progress thus far obtained. The subject of the fastening of the fabric to the airplane frame has also been investigated, and considerable improvement has resulted in the processes previously used. Extensive experiments are being conducted with the object of supplying the airplane designer with formulae and curves which will facilitate the designing of airplane fabrics for new airplanes, and it is intended to place fabric on the same basis as other constructional materials used in the airplane structure. The study of the use of silk fabric has also progressed with a view of providing a reserve material, should the supply of cotton fabrics fail as did the supply of linen fabrics. The study of balloon fabrics has comprised mainly the investigation of rubber films, as it is definitely known that the deterioration of that part of the material is such that investigations with a view to improvement in the cotton cloth are not warranted at this time. (See Report No. 39.)

D-2. A considerable amount of experimental work has been conducted at the Bureau of Standards by the subcommittee on steel construction for aircraft and the subcommittee on light alloys upon various alloys of aluminum and other light metallic elements, as well as upon heat-treated steels, with a view to the securing of uniform physical properties suitable for the purposes of airplane construction.

D-3. A survey has been made of the state of art of the application of pneumatic tires to airplanes and it is intended to make a further investigation of this subject.

E. *Generation of buoyant gases for lighter-than-air craft.*—Experiments of a confidential nature have been conducted by the Army and Navy upon the problem of the generation of hydrogen for observation balloons, scouting dirigibles, and other lighter-than-air craft. Investigations have been made as to the possibilities of hot air for this purpose. Attention is invited to Technical Reports Nos. 40 and 41, which describe work carried on at the Bureau of Standards.

F. *Nomenclature for aeronautics.*—The standardization of aeronautical nomenclature has been continued by the committee. The latest revision is contained in Technical Report No. 25. The subcommittee having this subject in charge has effected coordination of views between the Military and Naval Air Services of the United States and the aeronautical authorities of Great Britain.

G. *Specifications for aeronautical materials.*—During the war, when the Army and Navy were the only consumers of airplanes and their equipment, it was only proper that the Army and Navy should prepare the specifications for aeronautical materials. The committee, however, offered valuable advice to the military and naval authorities in connection with this subject.

H. *Bibliography of aeronautics.*—The Smithsonian Institution, in 1909, published a bibliography of aeronautics. The committee has extended this bibliography up to December 31, 1916, and this is in process of publication as a separate report. The committee proposes to keep this subject up to date by annual publications in the future.

I. *Collection, revision, and issuance of reports.*—This phase of the committee's activities is treated under the subject of the Office of Aeronautical Intelligence.

J. *Limitation of size of airplanes.*—Dr. de Bothezat, of the committee's technical staff, has made a serious study and has contributed a valuable article on the subject.

FINANCIAL REPORT.

The appropriation "National Advisory Committee for Aeronautics, 1917–18," carried in the naval appropriation act, approved March 4, 1917, is as follows:

> For scientific research, technical investigations, and special reports in the field of aeronautics, including the necessary laboratory and technical assistants; traveling expenses of members and employees; rent (office in the District of Columbia not to exceed $1,500); office supplies, printing, and other miscellaneous expenses; clerks; draftsmen; personal services in the field and in the District of Columbia: *Provided*, That the sum to be paid out of this appropriation for clerical, drafting, watchmen, and messenger service for the fiscal year ending June 30, 1918, shall not exceed $12,000; in all, $107,000.
>
> The balances under the several items of the appropriation "National Advisory Committee for Aeronautics" carried in the act making appropriations for the naval service for the fiscal year ending June 30, 1917, approved August 29, 1916, are hereby consolidated into a single fund and may be expended by the committee for its purposes as stated in the paragraph of public act No. 271, Sixty-third Congress, approved March 3, 1915, establishing the committee.

The above appropriation of $107,000, added to the continuing annual appropriation of $5,000 a year for five years, carried in the act establishing the committee, made a total of $112,000 available for the fiscal year 1918.

In order to provide funds for the completion of the committee's research laboratory at Langley Field, and for the construction of a wind tunnel building, the following amendment to the above appropriation was contained in the urgent deficiency act, approved October 6, 1917:

> National Advisory Committee for Aeronautics: Such portion of the appropriation "National Advisory Committee for Aeronautics" carried in the act making appropriations for the naval service for the fiscal year ending June 30, 1918, approved March 4, 1917, as may be necessary, not to exceed $40,000, is made available for the completion of the committee's research laboratory now under construction, and for the construction of additional buildings necessary in connection therewith.

To provide additional funds for rent of office in the District of Columbia, the following amendment to the appropriation for the fiscal year 1918 was contained in the urgent deficiency act, approved March 28, 1918:

> Naval Advisory Committee for Aeronautics: The limitation upon the amount which may be expended for office rent in the District of Columbia for the fiscal year 1918, contained in the naval appropriation act approved March 4, 1917, is increased from $1,500 to $2,332.

Out of the total appropriation of $112,000 for the expenses of the committee for the fiscal year 1918, the committee reports expenditures and obligations during the year amounting to the total of the appropriation, itemized as follows:

Expenditures and obligations incurred under the appropriation, "National Advisory Committee for Aeronautics, 1917–18."

Services (clerical, technical, and contract work)		$22,675.55
Equipment		38,185.53
Supplies		9,801.31
Transportation and communication		395.46
Travel		2,655.27
Building construction		32,055.20
Rent of office		2,331.68
Special reports:		
The application of the law of kinematic similitude to the design of airplanes [1]	$600.00	
Experimental researches on air propellers, II	1,500.00	
Investigation of the elements which contribute to statical and dynamical stability and of the effects of variations on those elements [1]	1,200.00	
The application of pneumatic tires to airplanes for the purposes of landing and taking the air, with suggestions regarding the ways and means of improving present practices in the same	500.00	
Translation of Italian publications	100.00	
		3,900.00
		112,000.00

APPROPRIATION FOR THE FISCAL YEAR, 1919.

Due to a decision rendered by the Comptroller of the Treasury on January 10, 1917, in which he held the National Advisory Committee for Aeronautics to be an independent Government establishment, the estimates for the fiscal year 1919 were referred to the Committee on Appropriations of the House of Representatives, instead of to the Committee on Naval Affairs, which formerly had jurisdiction.

The appropriation "National Advisory Committee for Aeronautics, 1919," carried in the sundry civil act, approved July 1, 1918, is as follows:

For scientific research, technical investigations, and special reports in the field of aeronautics, including the necessary laboratory and technical assistants; traveling expenses of members and employees; office supplies, printing, and other miscellaneous expenses; equipment, maintenance, and operation of research laboratory, and construction of additional buildings necessary in connection therewith; personal services in the field and in the District of Columbia: *Provided*, That the sum to be paid out of this appropriation for clerical, drafting, watchmen, and messenger service for the fiscal year ending June thirtieth, nineteen hundred and nineteen, shall not exceed $43,000; in all, $200,000, of which sum $10,300 shall be available for printing and binding the bibliography of aeronautics from July first, nineteen hundred and nine, to December thirty-first, nineteen hundred and sixteen: *Provided*, That the Secretary of War is authorized and directed to furnish office space to the National Advisory Committee for Aeronautics in governmental buildings occupied by the Signal Corps.

This appropriation became available July 1, 1918, and added to the continuing appropriation of $5,000 a year for five years, carried in the act establishing the committee, made a total of $205,000 available for the fiscal year 1919.

ESTIMATES FOR THE FISCAL YEAR 1920.

The following estimates of expenses for the fiscal year 1920 have been submitted by the committee in due form:

For scientific research, technical investigations, and special reports in the field of aeronautics, including the necessary laboratory and technical assistants; traveling expenses of members and employees; office supplies, printing and other miscellaneous expenses, including magazines and books of reference; equipment, maintenance, and operation of research laboratory and wind tunnel, and construction of additional buildings necessary in connection therewith; purchase, maintenance, and operation of one motor-propelled passenger-carrying vehicle; personal services in the field and in the District of Columbia: *Provided*, That the sum to be paid out of this appropriation for clerical, drafting, watchmen, and messenger service for the fiscal year ending June thirtieth, nineteen hundred and twenty, shall not exceed

[1] Published in third annual report.

$75,000; in all, $325,000: *Provided*, That the Secretary of War is authorized and directed to furnish office space to the National Advisory Committee for Aeronautics in such governmental building or buildings as may be deemed most appropriate for the conduct of the work of the National Advisory Committee for Aeronautics.

CONCLUSION.

The committee believes that the United States are destined to and should rightfully take the lead in the development of aviation for commercial as well as military purposes. There are, however, many problems in aviation which are still unsolved, to which reference is made in this report. Other problems will arise. The committee therefore emphasizes the need for continuous scientific research and experimentation in aeronautics. The great delays in getting an effective air force into action during the war were due in no small part to the lack of a proper scientific and technical foundation before the war.

The committee believes that it would be wise for the country to sustain an air service suitable for its immediate needs, but not a large force, as steady progress may be expected in the design of aircraft, and the civil and military services will require constantly in time of peace, but more especially in time of war, only the most improved types.

Looking to the healthy development of aeronautics in America for all purposes, the committee strongly recommends:

First. That support be given to the committee in its program for the further scientific study of the problems of flight, to which reference is made in this report.

Second. That a continuing comprehensive governmental policy regarding the construction of aircraft for both civil and military purposes be adopted, and that comparatively small orders be apportioned among competent aircraft manufacturers, thus assuring the existence of a nucleus of an aircraft industry capable of prompt and satisfactory response to military needs when the demand arises.

Third. That a plan of cooperation be formulated and approved whereby aviators in the military and naval services of the United States may receive continuous training in long-distance flying, and at the same time render effective service to the Nation by assisting in the work of the air mail service.

Fourth. That legislation be enacted for the regulation of civil aerial navigation, the issuance of licenses to pilots, inspection of machines, uses of landing fields, etc., and that such legislation be so drawn as to effectively encourage the development of commercial uses of aeronautics in the United States, and at the same time guide the development as far as practicable along such lines as will render immediate and effective military service to the Nation in event of war.

Fifth. That the estimates submitted by the War, Navy, and Post Office Departments be given full consideration with a view to placing America foremost in the development of aviation for all purposes.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
CHARLES D. WALCOTT,
Chairman, Executive Committee.